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Modeling of Rolling Element  
Bearing Mechanics

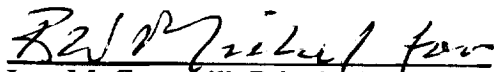
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User's Manual

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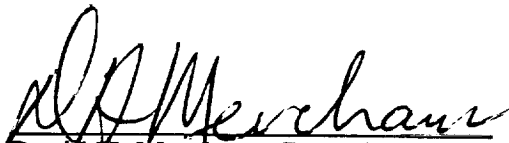
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## **1.0 INTRODUCTION**

This manual describes the use and operation of Version 1.10 of the NASA **Rolling Element **Bearing Analysis **System (REBANS)** family of computer programs. This analysis system offers improved capabilities to determine the response to external loads or displacements for three types of high-speed rolling element bearings:****

- angular contact ball bearings (single ball row),
- duplex angular contact ball bearings (dual ball row),
- cylindrical roller bearings.

The capabilities of the programs in this system are unique to the analysis of rolling element bearings in that the effects of bearing ring and support structure flexibility are included directly in the calculations. A finite element representation, prepared using Version 4.4 of ANSYS, is used for modeling of bearing rings and any support structure. The current analysis system, which can determine the response of the bearing and surrounding structure to quasi-static loading conditions, is composed of two main programs. These codes, which are referred to in separate chapters of this manual, may be briefly described as:

**PREBAN** – **PREprocessor for **Bearing Analysis**, used to create and modify the necessary input files for the main analysis program FEREB. PREBAN is run interactively, and provides extensive on-line help for all model definition commands. Input data is also examined for validity. All output files from this program are character based ASCII format, to enable transfer between various computing platforms.**

**FEREB** – **Flexibility Enhanced **Rolling Element **Bearing Analysis**, the main analysis code, reads the ASCII files prepared by PREBAN and performs the requested analysis. The program may be run either interactively or batch, and provides for command line arguments. All output results are written to an ASCII format file, which may be printed or edited to extract the desired analysis information.****

This manual is intended to provide an a complete description of how to prepare and run a complete bearing analysis using REBANS. Individual chapters explain how to run PREBAN and FEREB. For details of the theoretical formulation of the calculations, the reader is referred to a companion technical manual.

Two example problems are carried throughout the manual to illustrate the use of and output from the two main codes. Pertinent details of these examples will be given as needed, general descriptions are as follows:

Example #1 - 60 mm angular contact ball bearing with flexible outer ring and carrier, with 12 ball complement, subjected to axial and radial loads at speed. No inner ring model will be used.

Example #2 - 12 roller 73 mm cylindrical roller bearing with flexible outer ring and carrier, and flexible inner ring, with applied radial and centrifugal loads.

Both example problems have nonlinear deflections of the outer ring/carrier combination.

## **1.1 Types of Bearing Analyses Supported**

The REBANS system will currently determine the frictionless quasi-static equilibrium conditions for the two ball and one roller bearing types supported. Capability for analysis with friction has been provided for in the codes, however, this feature has not been implemented. The term quasi-static implies that speed effects are considered from the standpoint of centrifugal loads only. Other influences due to speed and friction, such as rolling element-cage interaction or gyroscopic moments, are not considered. Each rolling element is fixed at an equally spaced azimuthal position based on complement.

Primary input to a REBANS analysis is a set of 5-axes loads or displacements, applied to the inner ring, with the desired output an equivalent set of displacements or loads that satisfies static equilibrium. The five axes considered are the translations and rotations about perpendicular diametral axes of the bearing, and in the case of ball bearings, the fifth axis is axial motion. Roller bearings are not permitted axial displacements in this analysis, nor are any effects due to flange interactions considered.

REBANS essentially calculates the load-deflection characteristics of a bearing mounted in one of several ways. The most basic type of analysis is the response due to Hertzian deformation only, assuming the bearing inner and outer rings to be rigid. This is typically the only solution available with other rolling element bearing analysis programs. Normally, bearing rings are not rigid, and depending on the mounting conditions, may be quite flexible, especially with the outer ring. As such, the program provides three different arrangements for incorporating general ring and support flexibility:

- general bearing ring flexibility, with the outer and inner rings modeled as elastic components without any clearance with surrounding support structure,
- general ring flexibility including axial and radial clearance between the outer ring and any surrounding structure, and
- general ring and support flexibility with the bearing rings and any support structure modeled and elastic components with clearance between the outer ring and structure.

Specific details of the exact nature of the elastic models considered is given in Chapter 3. The mounting arrangements were chosen to provide a "control volume" representation of all the important features of a rolling element bearing. For example, some bearings may be mounted in rigid structures, in which case only the bearing rings would add any flexibility to the contact deformation. Other mounting configurations may have appreciable clearance between the outer ring and a flexible "carrier", which would require a model of both the outer ring and the structure. Use of the ANSYS finite element program permits very general models to be constructed and analyzed with REBANS. However, as described in Chapter 3, there are a few important node numbering conventions which must be followed.

With ball bearings, it is common to place a spring between the outer ring and housing to create a known compliance. This type of mechanical element, known as a preload spring, is also permitted in the analysis system.

## 1.2 Computing Platform Requirements

Both PREBAN and FEREBa were developed using ANSI Standard FORTRAN coding techniques targeting a 32-bit engineering workstation using the UNIX operating system. FEREBa has also been successfully tested on the NASA/MSFC Cray. There are a few machine dependent subroutine calls, for system utilities such as date, time, and command line arguments.

Current versions of both codes are much more dependent on core memory than any other hardware. When installed on a Silicon Graphics workstation, the programs require the following physical resources:

**Core Memory:** Approximately 4 million (32-bit) words for PREBAN, 8 million words for FEREBa

**Disk Space:** Neither PREBAN or FEREBa generate any scratch files. The main output files from PREBAN are ASCII data files, which can contain approximately 600 million characters at the largest problem size. FEREBa can create an extensive output file, the contents of which are solely at the discretion of the user. If maximum diagnostic output is requested for the largest problem size, this file can easily exceed 1 billion characters in length. Standard output from FEREBa will be only a few thousand characters.

**Execution Time:** PREBAN is an interactive program and requires very little time to complete any requested operation. FEREBa is normally run interactively as well, since the most computationally intensive calculations involve the reduction and inversion of the stiffness matrix to form the required compliance partitions. For large models, the matrix operations can require a few minutes, with roughly an equal amount of time to obtain the desired iterative quasi-static solution. The example problems in Chapter 5 list elapsed run times, and can be used as a guide for similar analyses.

Both PREBAN and FEREBa are supplied with each subroutine stored as a separate file, with 32 and 75 routines comprising PREBAN and FEREBa, respectively. To compile and load the programs, the *make* utility available with the UNIX operating system is the most convenient method, and both codes are supplied with *makefiles* for this purpose. Note that these *makefiles* also use the UNIX archive utility to store object files. When compiled, PREBAN may be loaded to an executable using only standard system routines. FEREBa, however, makes use of IMSL\* matrix and nonlinear equation solvers, and the *makefile* for FEREBa must be modified to specify the source of this math library.

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\* The IMSL MATH/LIBRARY is available from Visual Numerics, Inc.

## 2.0 OVERVIEW OF REBANS

REBANS was initially designed to provide three separate functions: preprocessing, analysis, and postprocessing. The Version 1.10 release has only the first two modules implemented – there is no explicit results processing program. A schematic of the overall operation of REBANS is shown in Figure 2-1 below:

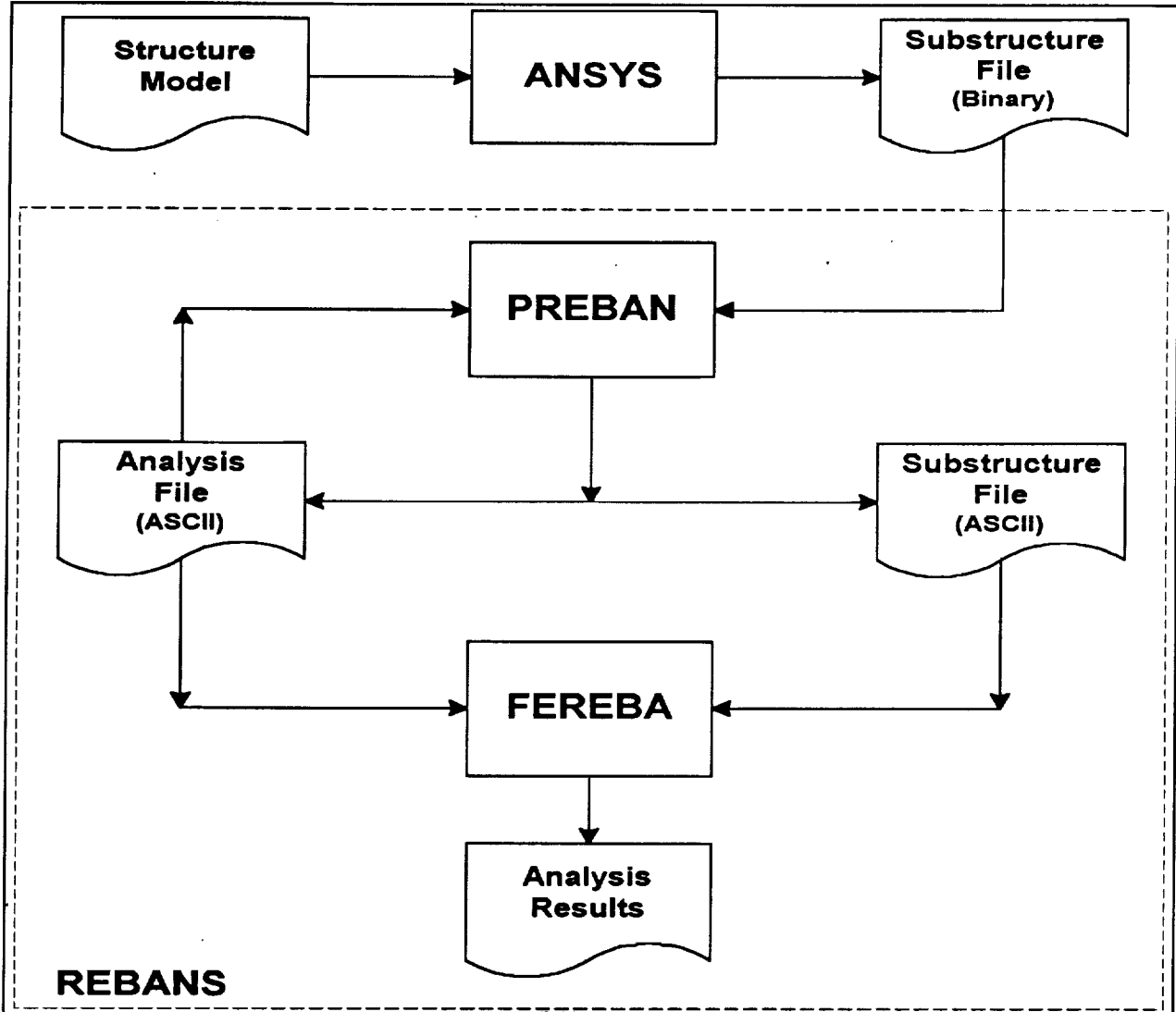


Figure 2-1 Overall Schematic of REBANS Operation

The general use of REBANS, as shown by Figure 2-1, begins with the creation of the appropriate ANSYS model of the bearing and surrounding structure to be analyzed. Note that in order to obtain a run with rigid rings using REBANS, it is not necessary to provide REBANS with an ANSYS model. Assuming a finite element model representation is desired, the model is created and substructured to the required master nodes in ANSYS for use with REBANS. Creation and substructuring ANSYS models will be discussed more fully in Chapter 3.



Having obtained any binary substructure files from ANSYS, the REBANS family of programs can now be used. The REBANS system is schematically denoted by the dashed-line box around the preprocessor program PREBAN, the main calculation program FEREBEA, and the associated data files. The main data file used by both PREBAN and FEREBEA is the analysis file, which is an ASCII file that contains all of the necessary parameters needed by FEREBEA to perform the analysis. PREBAN both reads and writes the analysis file. The only other information required by FEREBEA is the finite element model information, which is passed from ANSYS to PREBAN, converted to ASCII format, and then sent to FEREBEA. Note that all information transmitted to the FEREBEA is in the form of ASCII files, which means that FEREBEA may be placed on an entirely different computing system than either PREBAN or ANSYS.

## **2.1 Assumptions and Limitations**

REBANS was developed by making the following assumptions on the composition and behavior of the bearing system:

- All interaction forces are the result of elastic, frictionless contact
- Finite element models used to represent flexibility of the bearing rings and surrounding support structure will correspond to one of nine configurations for the outer ring and to one of three configurations for the inner ring
- Boundary conditions placed on finite element models must be consistent with the ring configuration selected
- Node numbers used with the finite element models will be chosen with a pattern that matches a predetermined order based on the ring configuration selected
- Loads placed on the bearing system are applied to the inner ring/shaft assembly, and consist of forces and moments in 5 orthogonal axes or displacements in the same axes, but not a combination of forces and displacements
- Cylindrical roller bearings are not permitted to generate any internal loads due to interaction between the rollers and flanges
- The inner ring of the bearing system can rotate at a given speed, and the outer ring is fixed and not free to rotate
- Temperatures of the bearing system components, once specified, will be held constant throughout the quasi-static equilibrium calculation
- Material properties used for bearing system components should be specified at operating temperatures and will be held constant throughout the quasi-static equilibrium calculation
- All clearances between components of the bearing system are uniform at each rolling element azimuthal position

Chapter 3 explains the different types of ring configurations handled by REBANS, and provides the required master node numbering scheme. The user is free to choose virtually any boundary condition, so long as the model fits one of the predefined ring configurations.

The following limits have also been placed on the problem to be analyzed:

- The bearing system to be analyzed must be either an angular contact ball bearing, a cylindrical roller bearing, or a duplex pair of angular contact ball bearings
- The total number of rolling elements in any bearing row is 20 (duplex can have a total of 40 balls, 20 in each bearing)
- Cylindrical roller bearings are not permitted any axial loads or displacements
- All finite element models must be created with ANSYS Version 4.4

## **2.2 Typical Steps in a REBANS Analysis**

There are several key steps in a typical REBANS analysis. Initially, if ring flexibility is desired, an ANSYS model must be created to represent the desired bearing geometry. The finite element model is then substructured and passed to the preprocessor program PREBAN, which converts the binary substructure file to ASCII format and writes an analysis file, containing necessary input data. The main calculation program FEREBE then reads the analysis and any substructure files, and performs the requested calculations. Results are contained in an output file for subsequent user review.

The ANSYS model, created using Version 4.4 of the code, must correspond to one of the prescribed ring configurations, which are described in Chapter 3. Careful attention must be given to master node numbers, since FEREBE assumes that a certain numbering scheme is used with the stiffness matrix. In ANSYS, all nodes must be rotated into a cylindrical coordinate system prior to creating elements. After the grid is created, boundary conditions are applied, master nodes are selected, and the model is then substructured using a standard ANSYS analysis procedure. The result from the substructuring will be a binary file, with a default name of FILE08.DAT, which is passed to PREBAN.

PREBAN interactively converts any substructure files and writes an analysis file. Note that the binary file created by ANSYS does not output the reduced stiffness matrix in any particular order, and PREBAN not only reads the ANSYS information but sorts the data into ascending node number order, as required by FEREBE. The analysis file is normally written by PREBAN after the user has entered all necessary data, however, PREBAN can also read the analysis file. This permits new files to be generated from previous versions. PREBAN also performs extensive checks on the data in the analysis file, and will advise the user if enough information is present in the model to permit a FEREBE analysis. Information required by PREBAN to build the analysis file is given in the next three subsections of this chapter. A printed summary of analysis parameters can be obtained from PREBAN, which may be sent directly to the screen or to a user defined file.

Using the analysis file and any converted substructure files, FEREBBA is then run either interactively or in batch mode. Substructure file names are contained in the analysis file, and FEREBBA can run without any ring models, in which case the analysis assumes the rings to be rigid. FEREBBA accepts command line arguments for analysis and output file names, alternatively, this information can be specified in batch mode using redirection. Output from FEREBBA consists of an ASCII file that contains the definition of the problem to be analyzed and results from the equilibrium calculation. The standard output file consists of 8 pages of listing formatted 80 characters wide by 60 lines per page. If additional printout options are requested, the output file can become very large.

Normally, after the FEREBBA run is finished, the REBANS analysis is complete. Additional load steps can be analyzed by editing the analysis file and re-running FEREBBA. Since the output from FEREBBA contains contact loads at each azimuthal position, this information can be back placed on the ANSYS to obtain stresses and graphically examine stresses for configurations which have fixed boundary conditions.

### **2.3 General Bearing Information Required**

The following general bearing information is required by REBANS in order to conduct an analysis, and is normally specified using PREBAN:

- Inner ring/shaft speed (in rpm, can be zero)
- Pitch diameter (diameter of rolling element centers)
- Number of rolling elements ( $\leq 20$ )
- Life multipliers for inner & outer ring (normally unity)
- Inner ring mean outer diameter
- Outer ring mean inner diameter
- Outer ring mean outer diameter
- Housing mean inner diameter
- Axial gap between outer ring and carrier
- Axial preload spring stiffness
- Material properties for shaft, inner ring, rolling elements, outer ring, and housing
- Loads or displacements applied to shaft/inner ring

In addition to the required information, optional data concerning temperatures of the shaft, inner ring, rolling elements, outer ring, and housing may also be specified. If no temperature data is given, room temperature is assumed.

## **2.4 Ball Bearing Information Required**

The following geometric information is required by REBANS in order to conduct an analysis with ball bearings:

- Ball diameter (all equal)
- Diametral clearance (can be negative)
- Outer and inner raceway curvatures, defined as

$$f_{o,i} = r_{o,i} / D$$

where  $f_{o,i}$  are the outer and inner curvatures,  $r_{o,i}$  are the outer and inner raceway groove radii, and  $D$  is the ball diameter

- Axial gap and stiffness of any spring between outer race and housing

If the bearing system being analyzed is a duplex, additional information is needed:

- Axial preload force
- Axial gap between primary and duplex bearings
- Distance between centers of primary and duplex bearings

In order to create an ANSYS model of a ball bearing, additional geometric data such as ring widths and land diameters will also be needed. Such information is usually found on a drawing of the bearing to be analyzed.

## **2.5 Roller Bearing Information Required**

The following geometric information is required by REBANS in order to conduct an analysis with roller bearings:

- Roller diameter (all equal)
- Diametral clearance (can be negative)
- Roller overall length (including any crowning)
- Roller crown radius
- Roller flat length (equal to overall length if no crowning)
- Effective outer & inner raceway lengths (includes effect of crowning)
- Outer & inner raceway crown radii (may be zero)

As with a ball bearing, the creation of an ANSYS model will require additional geometric data such as ring widths and chamfer dimensions, which is best taken from a drawing of the bearing to be analyzed.

### **3.0 ANSYS MODEL GENERATION**

The use of finite element models to include elastic effects into the quasi-static load and deflection calculations are the most significant feature of REBANS. These 3D models are used represent shafting, bearing inner and outer rings, and any supporting structure around the outer ring, commonly referred to as a carrier or isolator. The intent of the model should be to represent as much of the relevant bearing "control volume" for use in the analysis. The "control volume" can be as simple as just the inner and outer rings, or could be composed of detailed models of shafting and housing as well as the bearing rings. As with any finite element analysis, it is important that the analyst have a good understanding of the loads and boundary conditions involved before defining the extent of the representation. Virtually any physical system can be incorporated into REBANS because the analysis is conducted with substructured models.

REBANS uses two separate 3D finite element models – one for the inner ring and shafting, and the other for the outer ring and any carrier. It is not necessary to run REBANS with finite element models of either ring, in which case rigid rings will be assumed. For both single bearing configurations (i.e. ball or roller bearing but not duplex), a single outer or inner ring model can be used without a corresponding inner or outer ring companion model.

The next two subsections of this chapter describe the types of models accommodated by REBANS and the required numbering of specified master nodes. After the configurations have been explained, a third subsection describing how a model should be created and run using ANSYS is given. This information is provided as a summary for users unfamiliar with substructuring and master node concepts. The final three subsections in this chapter are actual ANSYS input decks used to create models for the examples discussed in this manual.

#### **3.1 Inner Ring Models**

For use in REBANS, the inner ring/shafting model *must* correspond to one of four prescribed configurations as listed in Table 3-1 below, one for each of the three bearing types considered and a traditional rigid-ring case.

Table 3-1 Prescribed Inner Ring Configurations

Inner Ring Configuration	Model Description
0	rigid ring, any bearing type (ball, roller, or duplex)
1	ball bearing, flexible or rigid shaft
2	duplex bearing set, flexible or rigid shaft
3	roller bearing, flexible or rigid shaft

For configuration 0, no substructured finite element model is required, and the analysis file written by PREBAN will indicate that the inner ring file is not available. For the three non-zero configurations, specific finite element files must be named in the analysis file, which will also indicate the type of inner ring configuration specified according to the numbers in Table 3-1. The

three flexible configurations are graphically illustrated in Figures 3-1 through 3-3. Numbers on the three figures refer to master nodes, and while it is not necessary to have node numbers in the models identical to those in the figures, *it is necessary that master nodes in the substructure model are incremented in the same order as the nodes in the figures*. In addition, the analysis assumes no flexibility or gap between the inner ring bore and the shaft outer diameter, which is usually the case for most installations.

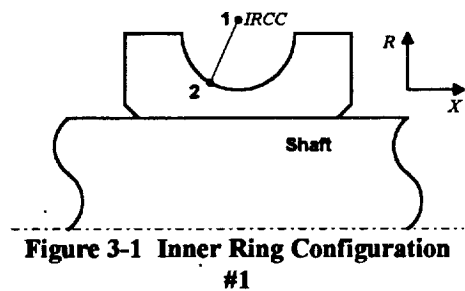


Figure 3-1 Inner Ring Configuration #1

The first flexible inner ring configuration is illustrated in Figure 3-1, which is a single ball bearing with a flexible (or rigid) shaft. Only two master nodes are used at each ball azimuthal position, with the first master at the inner race curvature center, labeled *IRCC* in the figure. The *IRCC* is the centerpoint of the arc used to define the inner raceway geometry, and can be established knowing either the nondimensional raceway curvature or the actual arc radius.

Displacements at the *IRCC* are obtained from the raceway by connecting the *IRCC* node to the raceway with rigid links. The second master node is defined at an assumed contact point on the inner raceway. Normally, this point can be set at an angle from the radial centerline equal to the mounted contact angle. The total number of master degrees of freedom (DOF) defined with the configuration will be 6 (six) times the number of rolling elements.

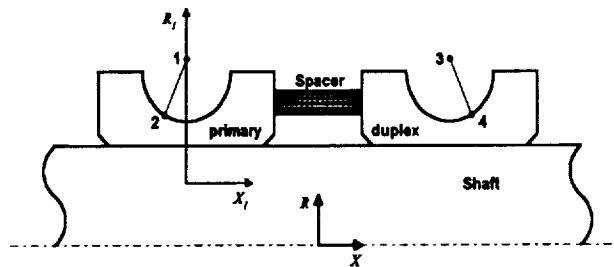


Figure 3-2 Inner Ring Configuration #2

Figure 3-2 shows the second flexible inner ring configuration, a duplex ball bearing set mounted on a flexible (or rigid) shaft. The number of elements in each pair of the duplex bearing must be equal. As the figure illustrates, the inner rings of the duplex pair are separated by a spacer, which can be modeled using ANSYS as a flexible or rigid connection. Note carefully the orientation and

numbering of the master DOF. Each azimuthal position of the duplex has four master nodes, for a total of 12 (twelve) DOF at each element location. The primary bearing is identical to the single ball bearing of configuration 1, whereas the duplex bearing *IRCC* is the next master DOF after the primary bearing contact node, with the final master the duplex contact node. The user is cautioned to follow the master DOF numbering scheme used in this configuration exactly.

As Figure 3-2 illustrates, the contact angle of the duplex bearing is opposite that of the primary bearing, thus the contact pattern of the duplex set handled by the analysis is an open or "O" configuration. Other loading patterns, such as crossed or "X" arrangement, are not considered by this version of REBANS.

Also shown in Figure 3-2 is the global *R-X* (radial-axial) coordinate system, which is placed at the geometric center of the duplex bearing. All specified inner ring loads or deflections are applied to

the bearing set at this location. For use in the equilibrium calculations, the overall forces or displacements are transferred to a coordinate system relative to the axial center of each bearing, which for the primary bearing is the  $R_1-X_1$  system. All output from the calculations is in the fixed,  $R-X$  inertial reference frame.

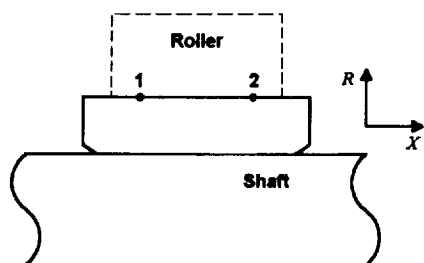


Figure 3-3 Inner Ring Configuration #3

The final flexible inner ring configuration handled by REBANS is shown in Figure 3-3, which is a single cylindrical roller bearing on a flexible (or rigid) shaft. This is similar to the first configuration for a single ball bearing, with two master DOF at each roller position. The equilibrium calculations assume that the axial positions of the master nodes are defined at locations equal to 60% of the roller effective length, thus the two nodes selected for mastering must lie 20% in from the active extent of the roller. The effective length of the roller is not usually the

total length due to roller end treatments. Force couples will be necessary to insure that loads applied to the two masters are distributed along the entire roller/raceway interface. The number of master DOF will be 6 (six) times the number of rollers in the bearing.

### 3.2 Outer Ring Models

Similar to the inner ring models, the outer ring/carrier model also *must* correspond to one of ten prescribed configurations as listed in Table 3-2 below. Each of the three supported bearing types has three associated outer ring/carrier configurations defined, for a total of nine possible structural models. A final rigid-ring case is also provided for comparison to traditional analyses.

Table 3-2 Prescribed Outer Ring Configurations

Outer Ring Configuration	Model Description
0	rigid ring, any bearing type (ball, roller, or duplex)
1	ball bearing, flexible outer ring and/or carrier, no deadband
2	ball bearing, flexible outer ring and deadband, rigid carrier
3	ball bearing, flexible outer ring and carrier, with deadband
4	duplex bearing set, flexible outer rings and/or carrier, no deadband
5	duplex bearing set, flexible outer rings and deadband, rigid carrier
6	duplex bearing set, flexible outer ring and carrier, with deadband
7	roller bearing, flexible outer ring and/or carrier, no deadband
8	roller bearing, flexible outer ring and deadband, rigid carrier
9	roller bearing, flexible outer ring and carrier, with deadband

For configuration 0, no substructured finite element model is required, and the analysis file will indicate that the outer ring file is not available. For the non-zero configurations, specific finite

element files must be named in the analysis file. The nine flexible configurations are graphically illustrated in Figures 3-4 through 3-12. The figures show not only the ring and structure geometry, but also indicate the *required* node numbering scheme. Since the finite element model required in REBANS uses a reduced number of degrees of freedom, *careful attention must be given to ordering the nodes such that the retained grid points (master degrees of freedom) are numbered in the sequence indicated by the figures.* The actual numbers are not important, just the order.

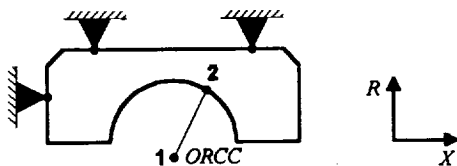


Figure 3-4 Outer Ring Configuration #1

Figure 3-4 illustrates the first outer ring configuration, corresponding to a single ball bearing with a flexible outer ring and/or carrier, constrained in both the radial and axial directions. Only two master nodes at each ball position are required with this configuration, the first at the outer race curvature center (ORCC), and the second at the outer race contact point.

The contact point is usually defined at an angle from the radial centerline equal to the mounted contact angle. This is a linear model, and will have 6 (six) times the number of balls as master DOF.

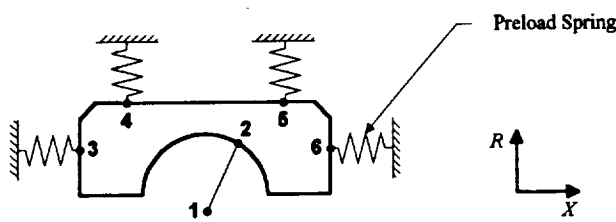


Figure 3-5 Outer Ring Configuration #2

The second outer ring model introduces nonlinear effects into the analysis. This configuration, shown in Figure 3-5, corresponds to a single ball bearing with flexible outer ring, with radial and axial clearance between the ring and carrier. In this model, the carrier is assumed to be rigid.

The radial gap is commonly known as deadband. On the loaded side of the bearing, the axial gap is permitted to have a spring between the ring and carrier, referred to as a preload spring. With this ring configuration, six master nodes are required. The first two are identical to the nodes in Configuration 1, the remainder are used to define the gaps. Although Figure 3-5 shows the outer ring connected at all four master nodes with springs, the actual ANSYS model is substructured without restraints (i.e., free-free). The user defined radial gap at master nodes 4 and 5 and the axial gap at master node 6 are assumed to be equal at all azimuthal positions. A large gap is set by the program at master node 3, to prevent unrestrained motion. The substructured ANSYS model will have 18 (eighteen) times the number of balls passed to REBANS as master DOF.

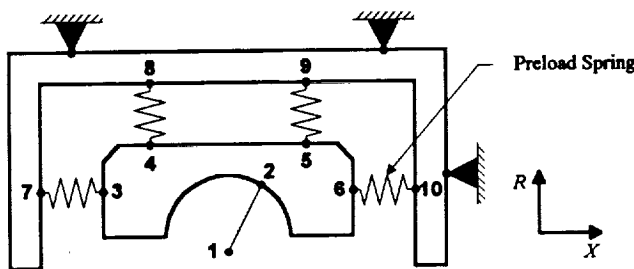


Figure 3-6 Outer Ring Configuration #3

The most complicated outer ring model for a single ball bearing is displayed in Figure 3-6. This configuration is similar to the previous model, except that both the outer ring and carrier are modeled as flexible structures. Appropriate nodes on the carrier are constrained in the radial and axial directions. A preload spring may also be used at the loaded axial gap. There are

a total of 10 master nodes in this configuration, with the required numbering sequence given in



the figure. The ten master nodes generate a total of 30 DOF per ball location in the ANSYS substructure model.

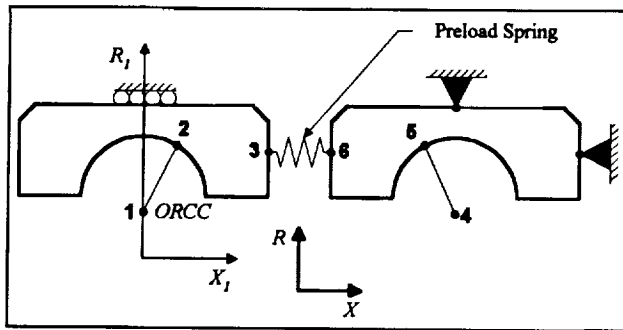


Figure 3-7 Outer Ring Configuration #4

Figure 3-7 illustrates the first duplex outer ring configuration handled by the program. This bearing set has flexible outer rings and carrier, without any deadband. The number of balls in each bearing is restricted to the same complement, and a preload spring can connect the two outer rings. If a preload analysis is desired, a corresponding inner ring model must also be supplied. Note that the boundaries are not the same on each outer ring. The primary bearing is allowed to

displace axially, subject only to the restraint provided by the preload spring. No radial motion is permitted, however. The duplex bearing is constrained both axially and radially. Notice also the master node numbering scheme, which is unique compared to the other 9 outer ring configurations. Each azimuthal position requires 6 master nodes; two for the curvature centers, two for the contact points, and the final two for the gap between outer rings.

The outer ring contact angle for all duplex bearings, as shown in Figures 3-7 through 3-9, is assumed by REBANS to be negative. This orientation corresponds to an open or "O" configuration. Other duplex orientations, such as a crossed or "X" arrangement, are not considered by this version of REBANS.

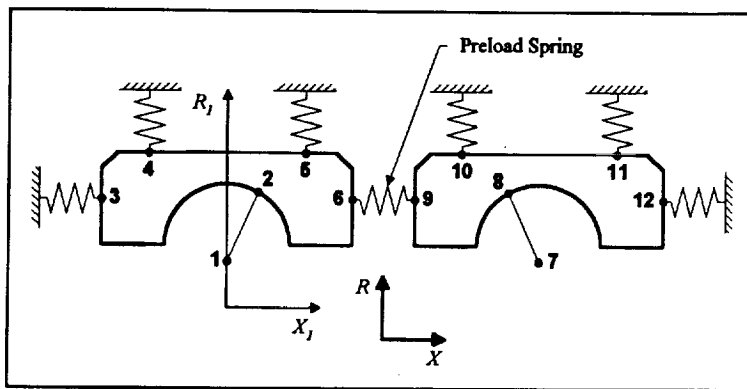


Figure 3-8 Outer Ring Configuration #5

The second duplex bearing configuration that can be analyzed is shown in Figure 3-8. This more general configuration permits both axial and radial gaps, and assumes that the carrier is rigid. A preload spring can be defined between the primary and duplex bearings. A total of seven nonlinear gaps are permitted with this model, four radial and three axial, although the gap at master node three is set by

the program to avoid unrestrained axial motion in the event of negative loads. A total of 12 (twelve) master nodes are used with this model, which results in 36 (thirty-six) DOF per azimuthal position. The ANSYS model of this configuration will be substructured with free-free boundary conditions, all connections to the rigid carrier will be applied by REBANS.

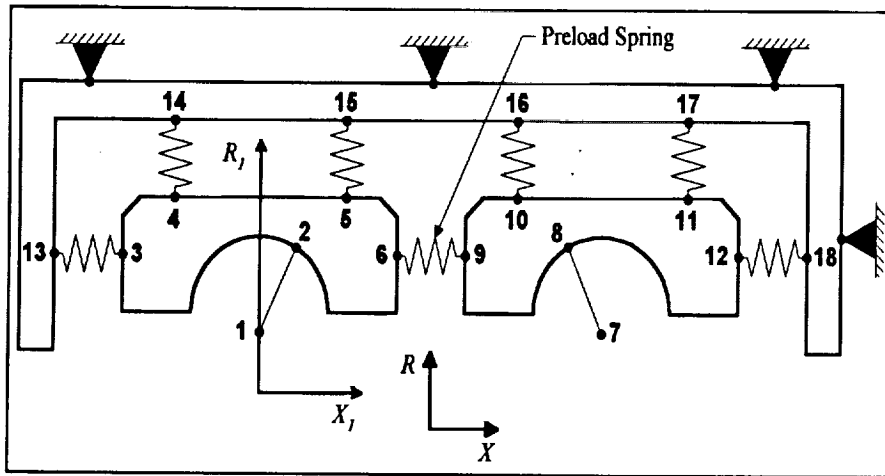


Figure 3-9 Outer Ring Configuration #6

Figure 3-9 illustrates the most complicated outer ring/carrier configuration that REBANS can accept. This duplex system has both flexible outer rings and a carrier, with seven total gaps, four radial and three axial. A preload spring can be placed between the two outer rings. The ANSYS model consists of three 6 master node

sub-structures of each outer ring and carrier, with the latter restrained radially and axially. The 18 master nodes of this configuration generate a total of 54 DOF at each azimuthal plane.

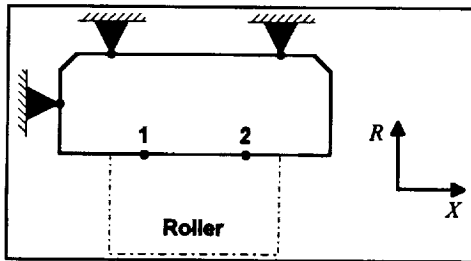


Figure 3-10 Outer Ring Configuration #7

Compared to the ball bearing configurations, the roller bearing models are more straightforward. Figure 3-10 shows the first outer ring roller bearing configuration handled by REBANS. This single cylindrical bearing is represented with a flexible outer ring and carrier, and is completely linear in response characteristics. Only two master DOF per roller are required, with the axial positions of the master nodes located at points corresponding to 60% of the roller effective length. Note that the model is shown restrained axially, which is

generally good practice, however, no axial loads are permitted with a roller bearing in REBANS.

With the three outer ring roller bearing configurations, forces are applied to the two raceway master nodes. However, this is not representative of the physical behavior of the load transmission, which occurs along a line equal to the effective roller length. To obtain such contact, node coordinate couples must be included in the ANSYS model linking nodes along the interface to the master nodes. This is illustrated in the subsection 3.5 roller bearing examples.

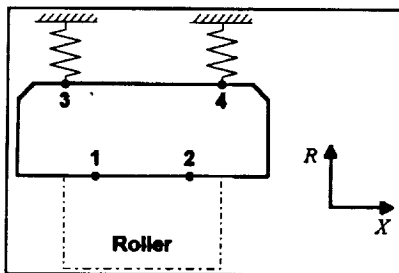


Figure 3-11 Outer Ring Configuration #8

The next roller bearing configuration is shown in Figure 3-11 and corresponds to a mounting arrangement with deadband. The carrier in this model is assumed rigid. A total of 4 master nodes per roller are required with this configuration, two at the roller-raceway interface, and two representing the gap between the outer ring and carrier. The two raceway master nodes must be selected at symmetric positions equal to 60% of the roller effective length. There is no similar position requirement on the outer ring gap nodes, however, the axial positions should be selected towards the end of the outer ring to properly consider

tilting effects. This model will be substructured in ANSYS with free-free boundary conditions, and will generate a total of 12 master DOF per roller.

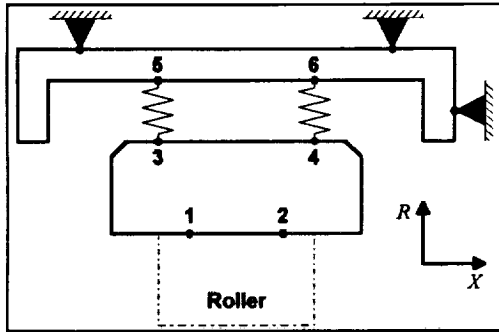


Figure 3-12 Outer Ring Configuration #9

The final outer ring configuration, illustrated in Figure 3-12, is the most general roller bearing model which consists of a flexible outer ring and carrier with radial deadband. In the ANSYS model, the outer ring and carrier comprise two separate pieces of the substructure, with the outer ring unconstrained and the carrier restrained radially and axially. Although the roller bearing is not permitted axial load, it is good practice to restrain the carrier in the axial direction. At each roller position, a total of 6 master nodes are defined, creating 18 master DOF per roller. As with the other roller

bearing models, the nodes on the raceway must be selected at axial positions corresponding to 60% of the roller effective length, or 20% in from the effective end of the roller.

Although the nine flexible outer ring configurations have been illustrated with simplified boundary conditions and geometries, it is permissible to create models with constraints that differ from the figures and still obtain valid results. As long as the overall intent of the model fits one of the nine prescribed configurations, REBANS will accept the substructure. For instance, the linear roller bearing configuration #7 can have the radial and axial restraints placed on the axial faces of the ring and carrier, permitted the outer diameter to flex radially. Another example of "intent" could be cited with any of the separate carrier models. In configuration #3, the carrier could be cantilevered from one location, which would satisfy the axial and radial restraints, although the motion produced by such a system would be quite different from a model with radial restraints placed over the bearing.

### **3.3 Creating and Running a Substructured ANSYS Model**

When work on REBANS was started, ANSYS Version 4.4 was chosen for the finite element model generator. Other programs can be used, however, the routines in PREBAN that read the binary substructure files created by ANSYS will almost certainly not read similar files from other programs. Since ANSYS has now upgraded to Version 5.0, the routines in PREBAN will probably need minor updates to read files created by this latest edition. FORTRAN source for these file I/O routines is usually provided with ANSYS.

It is assumed that the user is familiar with the operation of ANSYS and the use of the preprocessor PREP7 for creating finite element models. REBANS requires that any substructure passed from ANSYS have precisely 3 degrees of freedom (DOF) per node, which restricts element types used for modeling to 3D solids. Beam elements can be used, with the 3 rotational degrees of freedom reduced out when the model is substructured. In general, the elements of choice will be fully 3-dimensional with 3 DOF per node, such as STIF8 (spar), STIF45 (isoparametric brick), and STIF95 (quadratic brick). Based on experience, it is recommended that the STIF45 element be used whenever possible. If a model is created with several element types, particularly with 2D and 3D combinations, it is strongly advised that the final substructure be tested for static equilibrium prior to passing the model to REBANS.

To create a model for use in REBANS using ANSYS, the following steps are needed:

1. Decide what type of inner and outer ring configurations will be used, determine the applicable bearing "control volume", and obtain the necessary geometry data to describe the physical space.
2. Create ANSYS models of the inner ring/shaft and outer ring/carrier systems. It is strongly recommended that a cylindrical coordinate system be used to define nodes, although not required. *However, all nodes should be rotated into a cylindrical coordinate system prior to creating elements.* REBANS assumes that the substructured model is passed in the cylindrical system, any other system used will not result in valid answers. To rotate all nodes into a cylindrical system, a single command is all that is required.
3. Apply boundary conditions appropriate to the particular inner or outer ring configuration being analyzed. For inner ring models, axial and tangential restraints are required. For outer ring models, some configurations will not have any boundary conditions at all, others will have radial and axial restraints. All restraints are of the zero displacement type.
4. Select nodes for mastering, recalling that three degrees of freedom per node are required for all masters. Keep in mind also that the master node numbering sequence must agree with the selected inner or outer ring configuration. It is substantially easier to define nodes in a pattern such that masters can be selected in the correct order, however, renumbering can be used to place the nodes in proper sequence.
5. Run the substructuring analysis (KAN,7) to create the binary substructure file (FILE08.DAT). Since this version of REBANS only uses the stiffness matrix, the analysis option of KAY,6,0 can also be placed in the run stream.

All of the above steps in the procedure for creating ANSYS models is illustrated in the next two subsections for the single ball bearing and roller bearing example analyses. These example input files contain extensive comments which explain what is being defined. When reviewing these examples, pay particular attention to the use of ANSYS parameters to define constants, spars to connect ball bearing curvature centers to the raceways, node couples to connect roller bearing raceway nodes to masters, and the applied boundary conditions.

### **3.4 Ball Bearing Example ANSYS Model**

An example of a typical ANSYS run stream to create a substructured model is contained in this subsection for the first example problem, the 12 ball 60 mm angular contact bearing. Only the outer ring and carrier will be modeled, which is outer ring configuration #3. No inner ring model will be created. Although REBANS will run problems without an inner ring model provided, the final results may underpredict deflection, due to the absence of a flexible inner ring.

When using the ANSYS preprocessor PREP7, there are several ways to build a model and prepare an input deck for the main ANSYS analyzer. The method illustrated in this manual begins by creating an ASCII file which contains all of the necessary commands to build the model, and then the file is read into PREP7. This file contains a total of 269 lines, many of which are comments (denoted by the label /COM), and completely defines nodes and elements, applies constraints, selects master nodes, and inserts the requested substructure directives. The first 32 lines are:

```
1 /TITLE,Example Case 1, 12 ball 60mm Bearing, IBSCOR = 3
2
3 /COM Configuration for IBSCOR = 3, 6 masters per ball
4 /COM -----
5 /COM Model No. 1, 07 January 94 (Created from IBSCOR = 2 model)
6 /COM - Coarse grid definition, 2 elements thru thickness, 8 around
7 /COM raceway in circular pattern
8 /COM - NRE primary azimuthal planes, with 1 division between
9 /COM - Connection between ORCC & raceway thru 3D spars
10 /COM - Carrier modeled as simple channel, 2 elems thru thickness
11 /COM -----
12 /COM Define number of elements and primary azimuthal spacing
13 NRE = 12.
14 PAS = 360./NRE
15 MINC = 1000
16
17 /COM Set material properties for MAT code 1 (typical steel)
18 MP, EX , 1, 30.00E+6
19 MP, ALPX, 1, 8.00E-6
20 MP, NUXY, 1, .280
21 MP, GXY , 1, 11.72E+6
22 MP, DENS, 1, 7.33E-4
23 /COM Set material properties for MAT code 2 (another steel)
24 MP, EX , 2, 30.00E+6
25 MP, ALPX, 2, 8.00E-6
26 MP, NUXY, 2, .280
27 MP, GXY , 2, 11.72E+6
28 MP, DENS, 2, 7.33E-4
29
30 /COM Establish cylindrical coordinate system (R, theta, Z)
31 CSYS, 1
32
```

Note that three ANSYS parameters are defined in lines 13 – 15. NRE is the number of rolling elements (12), PAS is the azimuthal spacing ( $360^\circ/12 = 30^\circ$ ), and MINC is the main node numbering increment (1000). Lines 18 – 28 define two identical materials, with different material codes for display purposes. A cylindrical coordinate system is defined in line 31 with the CSYS command.

Lines 33 – 92 define outer ring nodes. The node numbering scheme is shown in lines 43 – 56, the explicitly defined nodes are listed in lines 60 – 73. Remaining nodes are created using FILL and NGEN commands. Line 91 rotates all nodes into the required cylindrical coordinate system.

```

33 /COM -----
34 /COM           Outer Ring Nodes & Elements
35 /COM -----
36 /COM Define required node locations for theta = 0 azimuthal plane,
37 /COM graphically depicted in the following figure. Note that first
38 /COM plane starts node numbers at 1001, second at 2001, etc.
39 /COM
40 /COM Revised node numbering from IBSCOR = 2 model
41 /COM -----
42 /COM
43 /COM           |
44 /COM           |--> z = 0
45 /COM           |
46 /COM           |-----|-----|-----|-----|
47 /COM           | 1024 *-----* 1028
48 /COM           | |         |         |         |
49 /COM           | |         | *1006   |         |
50 /COM           | |         | *1007   |         |
51 /COM           | |         | *1008   |         |
52 /COM           | |         | *1009   |         |
53 /COM           | |         | *-----* 1030
54 /COM           | |         |         |         |
55 /COM           | |         | * 1001   |         |
56 /COM           | |         |         |         |
57 /COM           |-----|-----|-----|-----|
58 /COM           R           Z           Location
59 /COM           -----
60 N, 1001, 1.8552, 0, 0.0           * ORCC
61 N, 1002, 2.0983, 0, -.3456       * Left side raceway break
62 N, 1003, 2.1888, 0, -.2592       * Left side raceway qtrpoint (.75*Z1002)
63 N, 1004, 2.2407, 0, -.1728       * Left side raceway midpoint (.5*Z1002)
64 N, 1005, 2.2688, 0, -.0864       * Left side raceway qtrpoint (.25*Z1002)
65 N, 1006, 2.2777, 0, 0.0           * Top of raceway
66 N, 1007, 2.2688, 0, +.0864       * Right side raceway qtrpoint (.25*Z1010)
67 N, 1008, 2.2407, 0, +.1728       * Right side raceway midpoint (.5*Z1010)
68 N, 1009, 2.1888, 0, +.2592       * Right side raceway qtrpoint (.75*Z1010)
69 N, 1010, 2.0983, 0, +.3456       * Right side raceway break
70 N, 1022, 2.0983, 0, -.6012       * Left end land
71 N, 1024, 2.5590, 0, -.6012       * Left end outer dia
72 N, 1028, 2.5590, 0, +.6012       * Right end outer dia
73 N, 1030, 2.0983, 0, +.6012       * Right end land
74
75 /COM Fill remaining node locations
76 FILL, 1022, 1024, 1, 1023, 1, 1   * Defines node 1023
77 FILL, 1024, 1028, 3, 1025, 1, 1   * Defines nodes 1025 - 1027
78 FILL, 1028, 1030, 1, 1029, 1, 1   * Defines node 1029
79 FILL, 1002, 1022, 1, 1012, 1, 9, 1 * Defines nodes 1012 - 1020
80
81 /COM Generate ORCC nodes at primary azimuthal planes (increment = MINC)
82 NGEN, NRE, MINC, 1001, , , 0, PAS, 0
83
84 /COM Generate outer ring nodes at primary and intermediate
85 /COM azimuthal planes (increment = MINC/2)
86 NGEN, 2*NRE, MINC/2, 1002, 1010, 1, 0, PAS/2., 0
87 NGEN, 2*NRE, MINC/2, 1012, 1020, 1, 0, PAS/2., 0
88 NGEN, 2*NRE, MINC/2, 1022, 1030, 1, 0, PAS/2., 0
89
90 /COM Rotate all nodes into cylindrical system
91 NROT, ALL
92

```

With the outer ring nodes defined, elements can be created. Lines 93 – 128 set material properties and element type (STIF45), and create all the elements for the outer ring. Note the use of ANSYS parameters to define the last section of elements in lines 119 and 120. For this model, a total of 384 elements will be created.

```

93 /COM -----
94 /COM All nodes for outer ring model now defined, create elements
95 /COM -----
96
97 /COM Associate material properties for element definition
98   MAT, 1
99
100 /COM Define element type 1 as STIF45 (3D solid brick), set active
101   ET, 1, 45
102   TYPE, 1
103
104 /COM Define first element at lower left corner of raceway (Element 1)
105   EN, 1, 1002, 1003, 1013, 1012, 1502, 1503, 1513, 1512
106
107 /COM Generate remaining inner row of elements around raceway
108   EGEN, 8, 1, 1 * Elements 2 - 8
109
110 /COM Generate outer row of elements from inner row
111   EGEN, 2, 10, 1, 8, 1 * Elements 9 - 16
112
113 /COM Use first 16 elements as pattern to generate almost all elements
114   EGEN, 2*NRE-1, MINC/2, 1, 16, 1 * Elements 17 - 80
115
116 /COM Define lower left corner element in last arc (note node numbers)
117 /COM      Element number is  $16*(2*NRE - 1) + 1 = NUME$ 
118 /COM      First node number is  $MINC*(NRE + 1/2) + 2 = NUMN$ 
119   NUME =  $16*(2*NRE-1)+1$ 
120   NUMN =  $MINC*(2*NRE+1)/2+2$ 
121   EN, NUME, NUMN, NUMN+1, NUMN+11, NUMN+10, 1002, 1003, 1013, 1012
122
123 /COM Generate inner row of elements in last arc
124   EGEN, 8, 1, NUME
125
126 /COM Generate last outer row of elements from inner row
127   EGEN, 2, 10, NUME, NUME+8, 1
128 /COM Last element number is  $16*(2*NRE)$ 
129

```

To link the curvature center to the motion at the raceway, 3D spars are used. The exact properties are not important, since the only function these elements serve is to transform motion from the raceway to the curvature centers. The definition of the spars is given in lines 131 – 137.

```

130 /COM Connect ORCCs to raceway using 3D spars
131   ET, 2, 8 * Linear 3D spar
132   TYPE, 2
133   R, 2, 0.10 * Value of area (arbitrary)
134   REAL, 2
135   EN, 401, 1001, 1006 * Spar element 401 from node 1001 to 1006
136   EN, 402, 1001, 1008 * Spar element 402 from node 1001 to 1008
137   EGEN, NRE, MINC, 401, 402 * Spar elements 403 - 424
138
139

```

The definition of the outer ring is now complete. Next, nodes and elements are defined for the carrier model. This process is very similar to that used for the outer ring. Lines 140 – 194 establish the nodes for the carrier.

```

140 /COM -----
141 /COM           Carrier Nodes & Elements
142 /COM -----
143 /COM Define required node locations for theta = 0 azimuthal plane,
144 /COM graphically depicted in the following figure. Note that first
145 /COM plane starts node numbers at 1102, second at 2102, etc.
146 /COM
147 /COM Gap between OR and carrier ID set to .010, axial gaps are .100,
148 /COM carrier is uniformly .400 thick
149 /COM -----
150 /COM
151 /COM
152 /COM                               |--> Z = 0
153 /COM                               |
154 /COM           1125                 |                 1127
155 /COM           1124*-----*-----*-----*-----*1128
156 /COM           |         *         *         *         *         |
157 /COM           |         *         *         *         *         |
158 /COM           1123*-----*-----*-----*-----*1129
159 /COM           |         *         |         1105         |         *         |
160 /COM           |         *         |         1107         |         *         |
161 /COM           |         |         |         |         |         |
162 /COM           1122*-----*-----*1102         |         1110*-----*-----*1130
163 /COM           |         1112         |         |         |         1120         |
164 /COM           |         |         |         |         |         |
165 /COM           |         |         |         |         |         |
166 /COM           R           Z           Location
167 /COM -----
168 N, 1102, 2.0000, 0, -0.7012 * Left side @ OR raceway
169 N, 1104, 2.5690, 0, -0.7012 * Left side OR (OD+.01)
170 N, 1108, 2.5690, 0, +0.7012 * Right side OR (OD+.01)
171 N, 1110, 2.0000, 0, +0.7012 * Right side @ OR raceway
172 N, 1122, 2.0000, 0, -1.1012 * Left end OR land
173 N, 1124, 2.9690, 0, -1.1012 * Left end carrier outer dia
174 N, 1128, 2.9690, 0, +1.1012 * Right end carrier outer dia
175 N, 1130, 2.0000, 0, +1.1012 * Right end OR land
176
177 /COM Fill remaining node locations
178 FILL, 1102, 1104, 1, 1103, 1, 1 * Defines node 1103
179 FILL, 1104, 1108, 3, 1105, 1, 1 * Defines nodes 1105 - 1107
180 FILL, 1108, 1110, 1, 1109, 1, 1 * Defines node 1109
181 FILL, 1122, 1124, 1, 1123, 1, 1 * Defines node 1123
182 FILL, 1124, 1128, 3, 1125, 1, 1 * Defines nodes 1125 - 1127
183 FILL, 1128, 1130, 1, 1129, 1, 1 * Defines node 1129
184 FILL, 1102, 1122, 1, 1112, 1, 9, 1 * Defines nodes 1112 - 1120
185
186 /COM Generate carrier nodes at primary and intermediate
187 /COM azimuthal planes (increment = MINC/2)
188 NGEN, 2*NRE, MINC/2, 1102, 1110, 1, 0, PAS/2., 0
189 NGEN, 2*NRE, MINC/2, 1112, 1120, 1, 0, PAS/2., 0
190 NGEN, 2*NRE, MINC/2, 1122, 1130, 1, 0, PAS/2., 0
191
192 /COM Rotate all nodes into cylindrical system
193 NROT, ALL
194

```



After the carrier nodes have been rotated into the cylindrical system, elements can be defined using a process similar to that used for the outer ring. Note the use of a different material number in line 201.

```

195 /COM -----
196 /COM All nodes for carrier model now defined, create elements, starting
197 /COM with element number 1001
198 /COM -----
199
200 /COM Associate material properties for element definition
201   MAT, 2
202
203 /COM Set element type 1 as STIF45 (3D solid brick), set active
204   TYPE, 1
205
206 /COM Define first element at lower left corner of raceway (Element 1001)
207   EN, 1001, 1102, 1103, 1113, 1112, 1602, 1603, 1613, 1612
208
209 /COM Generate remaining inner row of elements around raceway
210   EGEN, 8, 1, 1001                * Elements 1002 - 1008
211
212 /COM Generate outer row of elements from inner row
213   EGEN, 2, 10, 1001, 1008, 1    * Elements 1009 - 1016
214
215 /COM Use first 16 elements as pattern to generate almost all elements
216   EGEN, 2*NRE-1, MINC/2, 1001, 1016, 1    * Elements 1017 - 1080
217
218 /COM Define lower left corner element in last arc (note node numbers)
219 /COM      Element number is 16*(2*NRE - 1) + 1001 = NUME
220 /COM      First node number is MINC*(NRE + 1/2) + 102 = NUMN
221   NUME = 16*(2*NRE-1)+1001
222   NUMN = MINC*(2*NRE+1)/2+102
223   EN, NUME, NUMN, NUMN+1, NUMN+11, NUMN+10, 1102, 1103, 1113, 1112
224
225 /COM Generate inner row of elements in last arc
226   EGEN, 8, 1, NUME
227
228 /COM Generate last outer row of elements from inner row
229   EGEN, 2, 10, NUME, NUME+8, 1
230 /COM Last element number is 16*(2*NRE)+1001
231
232

```

With all of the outer ring and carrier elements defined, master nodes can be selected. Lines 238 - 245 specify nodes and degrees of freedom used for mastering.

```

233 /COM -----
234 /COM All elements have been generated, now establish master DOFs & BCs
235 /COM -----
236
237 /COM Define set of master DOFs for outer ring
238   M, 1001, UX, 1007, 6, UY, UZ    * Set nodes 1001 & 1007 as masters
239   MGEN, NRE, MINC, 1001, 1007, 6 * Define similar nodes as masters
240   M, 1023, UX, 1029, 2, UY, UZ    * Master nodes 1023, 1025, 1027, & 1029
241   MGEN, NRE, MINC, 1023, 1029, 2 * Define similar nodes as masters
242
243 /COM Define master DOFs for carrier
244   M, 1103, UX, 1109, 2, UY, UZ    * Master nodes 1103, 1105, 1107, & 1109
245   MGEN, NRE, MINC, 1103, 1109, 2 * Define similar nodes as masters
246

```

The final step is the specification of boundary conditions. The outer ring has no applied restraints, however, the carrier needs to be grounded. For this example, the entire outer periphery is selected in lines 247 – 252 and constrained to zero displacement in line 255. After applying the boundary conditions, all nodes and elements are returned to the active set in line 258. The final part of this input deck is the specification of analysis commands in lines 264 and 265.

```
247 /COM Fix outer boundaries of carrier, first select nodes on outer radius
248   NRSE, X, 2.90, 3.00
249
250 /COM Select nodes on left and right hand edges
251   NASE, Z, -1.20, -1.00
252   NASE, Z, +1.00, +1.20
253
254 /COM Fix all selected outer ring nodes
255   D, ALL, ALL, 0.0
256
257 /COM Restore all nodes & elements
258   NALL & EALL
259
260 /COM -----
261 /COM Model is complete, now insert analysis commands
262 /COM -----
263
264   KAN, 7           * Specify analysis type as substructure
265   KAY, 6, 0       * Generate stiffness matrix only
266
267 /COM -----
268 /COM End of model generation deck
269 /COM -----
```

This input file is directly submitted to the PREP7 processor using the /INPUT command. When the file has been read and processed, the model can be viewed using standard ANSYS plot commands. It is important to review the model graphically to verify geometry, master nodes, and applied boundary conditions. The final step in PREP7 is the creation of the analysis deck using the AFWRITE command.

### **3.5 Roller Bearing Example ANSYS Models**

The second example problem illustrates the use of ANSYS to create both inner and outer ring models. With a roller bearing, nodes on the raceway need to be coupled so that forces applied to the master nodes are distributed along the effective length of the roller/raceway interface. Both example ANSYS input decks illustrate this procedure.

The first model is for the inner ring, corresponding to configuration #3 (Figure 3-3), and contains 147 lines of input data. This is a relatively simple input deck, due in part to the less complicated geometry inherent with a roller bearing.

As with the ball bearing example, ANSYS parameters are used to define the number of elements, azimuthal spacing, and master increment. Only one material is defined, and all input will be entered using a cylindrical coordinate system. This information is contained in lines 1 – 26 of the following input file listing.

```

1 /TITLE,Example Case 2 Inner Ring, 12 roller 73mm Bearing, IBSCIR = 3
2
3 /COM Configuration for IBSCIR = 3, fixed ID, 2 masters on raceway
4 /COM -----
5 /COM Model No. 2, 16 July 93 (more elements axially)
6 /COM - Coarse grid, 2 elements thru thickness, 9 axially
7 /COM - NRE primary azimuthal planes, with 1 division between
8 /COM - Master nodes constrained to adjacent with couples, 6 total
9 /COM nodes on raceway
10 /COM -----
11
12 /COM Define primary azimuthal spacing, numbering increment
13 NRE = 12.
14 PAS = 360./NRE
15 MINC = 100
16
17 /COM Set material properties for MAT code 1 (typical steel)
18 MP, EX , 1, 30.00E+6
19 MP, ALPX, 1, 8.00E-6
20 MP, NUXY, 1, .280
21 MP, GXY , 1, 11.72E+6
22 MP, DENS, 1, 7.33E-4
23
24 /COM Establish cylindrical coordinate system (R, theta, Z)
25 CSYS, 1
26

```

Next node locations for the 0° azimuthal position are defined, based on the numbering scheme shown in the figure illustrated in lines 36 – 49.

```

27 /COM -----
28 /COM Define required node locations for theta = 0 azimuthal plane,
29 /COM graphically depicted in the following figure. Note that first
30 /COM plane starts node numbers at 101, second at 201, etc.
31 /COM
32 /COM Node numbering for rows thru thickness increments by 10. Model
33 /COM no. 2 added nodes between end of roller and ring (102 & 109).
34 /COM -----
35 /COM
36 /COM
37 /COM |
38 /COM | |---> Z' = 0
39 /COM |
40 /COM | 102 103 104 105 | 106 107 108 109
41 /COM | *-----*-----*-----*-----*
42 /COM | / M M \
43 /COM | 101 * | 110
44 /COM | | |-----| | 120
45 /COM | | |-----| |
46 /COM | 121 * | 130
47 /COM | \ |-----| /
48 /COM | *-----*-----*-----*
49 /COM | 122 | 129
50 /COM

```

Actual nodes are defined in lines 51 - 73, and then rotated into the cylindrical system with the command given in line 75. Two coupled node sets are defined in lines 78 and 79, which ties nodes adjacent to the masters.

```

51 /COM          R          Z          Location
52 /COM          -----
53  N, 101, 1.6732, 0, -.5638      * Left edge of inner ring
54  N, 102, 1.6732, 0, -.5138      * Left side raceway break (no chmfr)
55  N, 103, 1.6732, 0, -.2953      * Left extent of effective roller length
56  N, 104, 1.6732, 0, -.1772      * 20% in from roller left end (Master)
57  N, 107, 1.6732, 0, +.1772      * 20% in from roller right end (Master)
58  N, 108, 1.6732, 0, +.2953      * Right extent of effective roller length
59  N, 109, 1.6732, 0, +.5138      * Right side raceway break (no chmfr)
60  N, 110, 1.6732, 0, +.5638      * Right edge of inner ring
61  N, 121, 1.5000, 0, -.5638      * Left end ID edge break (.060 chmfr)
62  N, 122, 1.4370, 0, -.5038      * Left end inner dia
63  N, 129, 1.4370, 0, +.5038      * Right end inner dia
64  N, 130, 1.5000, 0, +.5638      * Right end ID edge break (.060 chmfr)
65
66 /COM Fill remaining node locations
67  FILL, 104, 107, 2, 105, 1, 1      * Defines nodes 105 & 106
68  FILL, 122, 129, 6, 123, 1, 1      * Defines nodes 123 - 128
69  FILL, 101, 121, 1, 111, 1, 10, 1  * Defines nodes 111 - 120
70
71 /COM Generate remaining nodes at azimuthal planes (increment = MINC/2)
72  NGEN, 2*NRE, MINC/2, 101, 130, 1, 0, PAS/2., 0
73
74 /COM Rotate all nodes into cylindrical system
75  NROT, ALL
76
77 /COM Couple adjacent nodes to intended masters
78  CP, 1, UX, 104, 103, 105      * Couple set 1 - node 104
79  CP, 2, UX, 107, 106, 108      * Couple set 2 - node 107
80
81 /COM Generate remaining couples from first 2
82  CPSGEN, NRE, MINC, 1, 2, 1
83

```

With all the nodes defined, elements can be created. The first block of elements is defined in lines 95 - 102, using 3D brick (STIF45) elements.

```

84 /COM -----
85 /COM All nodes for outer ring model now defined, create elements
86 /COM -----
87
88 /COM Associate material properties for element definition
89  MAT, 1
90
91 /COM Define element type 1 as STIF45 (3D solid brick), set active
92  ET, 1, 45
93  TYPE, 1
94
95 /COM Define first element at lower left corner of raceway
96  EN, 1, 101, 102, 112, 111, 151, 152, 162, 161      * Element 1
97
98 /COM Generate remaining inner row of elements around raceway
99  EGEN, 9, 1, 1      * Elements 2 - 9
100
101 /COM Generate outer row of elements from inner row
102  EGEN, 2, 10, 1, 9, 1      * Elements 10 - 18
103
104 /COM Use first 18 elements as pattern to generate almost all elements
105  EGEN, 2*NRE-1, MINC/2, 1, 18, 1

```

Remaining elements are defined based on the pattern of the first block. Then boundary conditions are applied, which are axial and tangential restraints at the bore. Finally, master nodes are selected and the substructure commands are inserted.

```

106
107 /COM Define lower left corner element in last arc (note node numbers)
108 /COM      Element number is  $18*(2*NRE - 1) + 1 = CRNE = 415$ 
109 /COM      First node number is  $MINC*(NRE + 1/2) + 1 = BEGN = 1251$ 
110      CRNE =  $18*(2*NRE-1)+1$ 
111      BEGN =  $MINC*(2*NRE+1)/2+1$ 
112      EN, CRNE, BEGN, BEGN+1, BEGN+11, BEGN+10, 101, 102, 112, 111
113
114 /COM Generate inner row of elements in last arc
115      EGEN, 9, 1, CRNE
116
117 /COM Generate last outer row of elements from inner row
118      EGEN, 2, 10, CRNE, CRNE+8, 1
119 /COM Last element number is  $18*(2*NRE) = 432$ 
120
121 /COM -----
122 /COM All elements have been generated, now establish BCs & master DOFs
123 /COM -----
124
125 /COM Select nodes on bore
126      NRSE, X, 1.40, 1.45
127
128 /COM Fix all selected bore nodes axially and tangentially
129      D, ALL, UY, 0.0, , , , UZ
130
131 /COM Restore all nodes & elements
132      NALL & EALL
133
134 /COM Define set of master DOFs
135      M, 104, UX, 107, 3, UY, UZ      * Set nodes 104 & 107 as masters
136      MGEN, NRE, MINC, 104, 107, 3    * Define similar nodes as masters
137
138 /COM -----
139 /COM Model is complete, now insert analysis commands
140 /COM -----
141
142      KAN, 7          * Specify analysis type as substructure
143      KAY, 6, 0      * Generate stiffness matrix only
144
145 /COM -----
146 /COM End of model generation deck
147 /COM -----

```

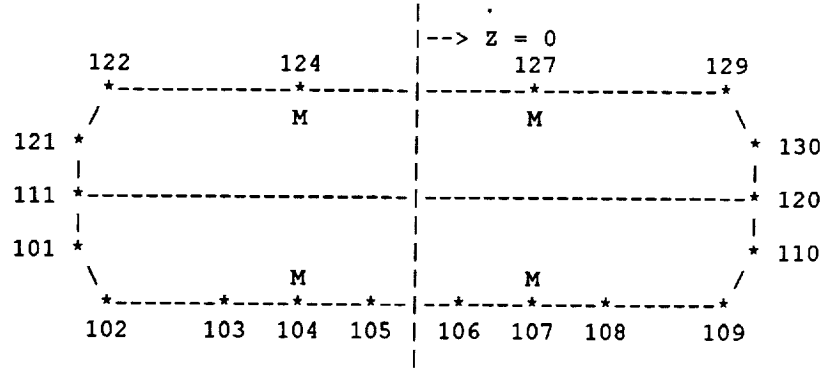
This deck is now ready to be submitted to the PREP7 processor. After verifying geometry, node coupling, boundaries, and the selected masters, the model is prepared for ANSYS execution by using the AFWRITE command.

The last ANSYS input deck is the companion model for the outer ring of the roller bearing example. This corresponds to an outer ring configuration #8 (Figure 3-11), which considers the carrier to be rigid and does not include any restraints on the outer ring. The first 50 lines of this deck define parameters, materials and illustrate the node numbering scheme.

```

1 /TITLE,Example Case 2 Outer Ring, 12 roller 73mm Bearing, IBSCOR = 8
2
3 /COM Configuration for IBSCOR = 8, free-free, 4 total masters
4 /COM -----
5 /COM Model No. 2, 16 July 93 (more elements axially)
6 /COM - Coarse grid, 2 elements thru thickness, 9 axially
7 /COM - NRE primary azimuthal planes, with 1 division between
8 /COM - Master nodes constrained to adjacent with couples, 6 total
9 /COM nodes on raceway
10 /COM -----
11
12 /COM Define primary azimuthal spacing, numbering increment
13 NRE = 12.
14 PAS = 360./NRE
15 MINC = 100
16
17 /COM Set material properties for MAT code 1 (typical steel)
18 MP, EX , 1, 30.00E+6
19 MP, ALPX, 1, 8.00E-6
20 MP, NUXY, 1, .280
21 MP, GXY , 1, 11.72E+6
22 MP, DENS, 1, 7.33E-4
23
24 /COM Establish cylindrical coordinate system (R, theta, Z)
25 CSYS, 1
26
27 /COM -----
28 /COM Define required node locations for theta = 0 azimuthal plane,
29 /COM graphically depicted in the following figure. Note that first
30 /COM plane starts node numbers at 101, second at 201, etc.
31 /COM
32 /COM Node numbering for rows thru thickness increments by 10. Model
33 /COM no. 2 added nodes between end of roller and ring (102 & 109).
34 /COM -----
35 /COM
36 /COM
37 /COM
38 /COM
39 /COM
40 /COM
41 /COM
42 /COM
43 /COM
44 /COM
45 /COM
46 /COM
47 /COM
48 /COM
49 /COM
50 /COM

```



Node locations, in the cylindrical coordinate system established in line 25, are defined explicitly and by using FILL and NGEN commands. All of the nodes are rotated into the cylindrical system using the command in line 75, and the master node couples are established in lines 78, 79, and 82. The first 18 elements are then defined beginning at the 0° azimuthal plane.

```

51 /COM          R          Z          Location
52 /COM          -----
53  N, 101, 2.3000, 0, -.6012  * Left edge of outer ring
54  N, 102, 2.2638, 0, -.5512  * Left side raceway break (.050 chmfr)
55  N, 103, 2.2638, 0, -.2953  * Left extent of effective roller length
56  N, 104, 2.2638, 0, -.1772  * 20% in from roller left end (Master)
57  N, 107, 2.2638, 0, +.1772  * 20% in from roller right end (Master)
58  N, 108, 2.2638, 0, +.2953  * Right extent of effective roller length
59  N, 109, 2.2638, 0, +.5512  * Right side raceway break (.050 chmfr)
60  N, 110, 2.3000, 0, +.6012  * Right edge of outer ring
61  N, 121, 2.4400, 0, -.6012  * Left end OD edge break (.060 chmfr)
62  N, 122, 2.5000, 0, -.5412  * Left end outer dia
63  N, 129, 2.5000, 0, +.5412  * Right end outer dia
64  N, 130, 2.4400, 0, +.6012  * Right end OD edge break (.060 chmfr)
65
66 /COM Fill remaining node locations
67  FILL, 104, 107, 2, 105, 1, 1          * Defines nodes 105 & 106
68  FILL, 122, 129, 6, 123, 1, 1          * Defines nodes 123 - 128
69  FILL, 101, 121, 1, 111, 1, 10, 1      * Defines nodes 111 - 120
70
71 /COM Generate remaining nodes at azimuthal planes (increment = 50)
72  NGEN, 2*NRE, 50, 101, 130, 1, 0, PAS/2., 0
73
74 /COM Rotate all nodes into cylindrical system
75  NROT, ALL
76
77 /COM Couple adjacent nodes to intended masters
78  CP, 1, UX, 104, 103, 105          * Couple set 1 - node 104
79  CP, 2, UX, 107, 106, 108          * Couple set 2 - node 107
80
81 /COM Generate remaining couples from first 2
82  CPSGEN, NRE, MINC, 1, 2, 1
83
84 /COM -----
85 /COM All nodes for outer ring model now defined, create elements
86 /COM -----
87
88 /COM Associate material properties for element definition
89  MAT, 1
90
91 /COM Define element type 1 as STIF45 (3D solid brick), set active
92  ET, 1, 45
93  TYPE, 1
94
95 /COM Define first element at lower left corner of raceway
96  EN, 1, 101, 102, 112, 111, 151, 152, 162, 161  * Element 1
97
98 /COM Generate remaining inner row of elements around raceway
99  EGEN, 9, 1, 1          * Elements 2 - 9
100
101 /COM Generate outer row of elements from inner row
102  EGEN, 2, 10, 1, 9, 1          * Elements 10 - 18
103

```

With the first 18 elements defined, the remaining elements can be generated using the EGEN command and two parameters for node and element numbers. Master nodes are then selected, but no displacement boundaries are given, since this is a free-free model. The required substructuring analysis commands are inserted at the end of the deck.

```

104 /COM Use first 18 elements as pattern to generate almost all elements
105     EGEN, 2*NRE-1, MINC/2, 1, 18, 1          * Elements 19...
106
107 /COM Define lower left corner element in last arc (note node numbers)
108 /COM     Element number is 18*(2*NRE - 1) + 1 = CRNE = 415
109 /COM     First node number is MINC*(NRE + 1/2) + 1 = BEGN = 1251
110     CRNE = 18*(2*NRE-1)+1
111     BEGN = MINC*(2*NRE+1)/2+1
112     EN, CRNE, BEGN, BEGN+1, BEGN+11, BEGN+10, 101, 102, 112, 111
113
114 /COM Generate inner row of elements in last arc
115     EGEN, 9, 1, CRNE
116
117 /COM Generate last outer row of elements from inner row
118     EGEN, 2, 10, CRNE, CRNE+8, 1
119 /COM Last element number is 18*(2*NRE) = 432
120
121 /COM -----
122 /COM All elements have been generated, now establish master DOFs
123 /COM -----
124
125 /COM Define set of master DOFs
126     M, 104, UX, 107, 3, UY, UZ          * Set nodes 104 & 107 as masters
127     MGEN, NRE, MINC, 104, 107, 3      * Define similar nodes as masters
128     M, 124, UX, 127, 3, UY, UZ          * Also set nodes 124 & 127 as masters
129     MGEN, NRE, MINC, 124, 127, 3      * Add other similar nodes
130
131 /COM -----
132 /COM Model is complete, now insert analysis commands
133 /COM -----
134
135     KAN, 7          * Specify analysis type as substructure
136     KAY, 6, 0      * Generate stiffness matrix only
137
138 /COM -----
139 /COM End of model generation deck
140 /COM -----

```

This outer ring input deck, along with the previously discussed inner ring file, will generate ANSYS binary substructure files which are processed by PREBAN.



## 4.0 USE INSTRUCTIONS FOR PREBAN

The PREBAN preprocessor for REBANS was designed as a standalone package to enable separate computing systems to build and run the complete analysis. PREBAN is designed to be run interactively, although a redirected input file can be used for execution in batch mode. All information produced by PREBAN is in ASCII format. As Figure 2-1 illustrates, two files are created for use by the main analysis code FEREBAN:

- The analysis file, containing problem definition, geometry, material, temperature and load/deflection data. This file is named REBANS.DAT if not explicitly defined by the user.
- The converted substructure file(s) from ANSYS, which must be given a new name before PREBAN will generate the file.

It is not necessary to start from scratch each time PREBAN is run. Previously created analysis files can be read by PREBAN and a new file subsequently written. Even different bearing types can be used as input (i. e., input a ball bearing file, create a roller bearing file). The first user input required is the response for use of a previously created analysis file.

### 4.1 Operating PREBAN

Once the analysis file source has been determined, the main input menu of PREBAN is reached. The program prompt appears as:

-----  
Enter processing option (A-D,F-H,L,M,O-U,W,Z), ? for HELP, or Q to Quit

All parameters necessary to define an analysis model are entered via a single character command. Entering H or ? outputs the top level help information:

Help option entered; The following are valid options:

A - Specify Analysis Options	O - Output Request
B - Define Ball Bearing Parameters	P - Plot Request
C - Define Control Parameters	Q - Quit (Terminate Execution)
D - Specify Applied Displacements	R - Define Roller Bearing Parameters
F - Finite Element Model File Names	S - Print Model Summary
G - Define General Parameters	T - Specify Temperatures
H - Help option (same as ?)	U - Specify Unit System
L - Specify Applied Loads	W - Write Analysis File
M - Define Material Properties	Z - Zap Currently Defined Model

For HELP with a specific option, enter the option letter followed by a separator <; , /> and a ? as in G,? for help on the G option

Enter the option letter only for full prompt mode

To reset an option, enter the option letter followed by a separator and nothing else as in L, which will clear values set for the L option

Note that in addition to this top level help, each option also has specific help information. Besides the definition options, the S option for model summary is very convenient for determining what information has been entered and if the model is sufficiently defined to run. The W option allows writing an analysis file at any time, whether complete or not (a warning will be issued if not complete). Although present, the P option for plotting is not active (e.g. no plotting capability exists). The following subsection describes the required input for all of the active options. If applicable, valid input ranges for the variables are listed.

## **4.2 Required Input to PREBAN**

Since PREBAN is an interactive program, there is no specific input stream. Starting the program without a previously created analysis file requires significantly more input than to just modify an existing deck. Required information for the processing options can be determined by using the specific help for each option. Data for a specific option can be entered (in order) on the command line, separated by semicolons, commas, or forward slashes (/). The program can be also directed to prompt for input by just entering the letter of the option. Most users will find the prompt mode to be much easier for entering data than trying to remember what parameters must be placed after the option letter. The prompt mode also displays any units and a default value for each parameter. In alphabetical order, the following information is required to be entered for each processing option.

### **Processing Option "A" – Analysis Options**

This option specifies overall FEREB A analysis options, including iteration loop limits and required accuracy, output units, and print option. The print option is normally set to 0 (zero) for standard output, setting values of 1-3 will generate increasing amounts of debug information. If the help option is entered, the following information will be output:

#### Help for Analysis Option Definition

7 parameters are currently require specification:

- 1 - Analysis type (must be = 1 right now)
- 2 - Analysis output units (English = 0, Metric= 1)
- 3 - Ring Disp iteration limit (suggested value = 10)
- 4 - Ring Disp iteration percent error (suggested value = .01)
- 5 - Force iteration limit (suggested value = 100)
- 6 - Force iteration percent error (suggested value = .001)
- 7 - Analysis print option
  - 0 = standard output (default, no debug)
  - 1 = partial analysis debug output
  - 2 = full analysis debug output
  - 3 = verbose analysis debug output (not recommended)

The suggested values for iteration parameters are program defaults. Depending on the problem being analyzed, these values may require modification. Note that the iteration errors are relative and are entered in percent. Refer to Chapter 5 for more information on iteration parameters.

### Processing Option "B" – Ball Bearing Parameters

This option defines specific parameters for use with ball bearings. Four quantities are required to be input, as listed when the help option is requested:

Help for Ball Bearing Parameter Definition

4 parameters require specification:

- 1 - Ball Diameter [in]
- 2 - Diametral Clearance [in]
- 3 - Outer Race Curvature
- 4 - Inner Race Curvature

Each one of these four parameters are checked by PREBAN for validity. Note that units are included in the first two variables, in this case in the English system. If the metric system for input was selected, the units would be millimeters.

### Processing Option "C" – Analysis Configuration

The particular type of bearing and ring configuration are defined with this option. The three input parameters are listed by using the help option:

Help for Analysis Configuration Definition

3 parameters are currently require specification:

- 1 - Bearing Type Designator
    - 0 = ball bearing (default)
    - 1 = roller bearing
    - 2 = duplex ball bearing set
  - 2 - Outer Ring Configuration (0 - 9, 0 = rigid)
  - 3 - Inner Ring Configuration (0 - 3, 0 = rigid)
- Refer to User Manual for Nonzero Ring Configurations

The outer and inner ring configurations correspond to Figures 3-4 through 3-12 for the outer ring and Figures 3-1 through 3-3 for the inner ring.

### Processing Option "D" – Applied Displacements

This option, along with the "L" option, are the means to apply forces the the bearing system. Specifying displacements with this option eliminates the iteration for inner ring force equilibrium, although elastic deflections are still determined iteratively. There is no check made to insure that the displacements specified will result in a valid solution. The five input displacements correspond to the five axes of inner ring motion:

Help for Applied Displacement Definition

5 parameters require specification:

- 1 - X-Axis (Axial) Disp [in]
- 2 - Y-Axis (Radial) Disp [in]
- 3 - Z-Axis (Radial) Disp [in]
- 4 - XZ-plane Rotation [rad]
- 5 - YZ-plane Rotation [rad]

### Processing Option "F" – Finite Element Substructure File(s)

This option controls the reading of the binary FILE08.DAT from ANSYS and the output of a sorted ASCII file with the substructure information. ASCII file names present in the analysis file will be used as defaults. Up to four files may be specified:

Help for Finite Element Model Data Files

A maximum of 4 data files require specification:

- 1 - Name of Outer Ring ANSYS FILE08 (may be blank)
- 2 - Name of Inner Ring ANSYS FILE08 (also may be blank)
- 3 - Desired Name of Outer Ring ASCII File
- 4 - Desired Name of Inner Ring ASCII File

ASCII files written only if valid FILE08 input

When reading and writing the substructure data, several messages are output to the screen, advising the user of progress. This text should be reviewed carefully for any errors in the conversion process.

### Processing Option "G" – General Bearing Parameters

This option is used to specify general parameters for the bearing system, such as geometry, number of rolling elements, and inner ring speed. The required data is context sensitive with respect to the type of bearing specified with the "C" option. For a duplex ball bearing type, which requires the most input data, the following information is required:

Help for General Bearing Parameter Definition

14 parameters require specification:

- 1 - Shaft Speed [rpm]
- 2 - Pitch Diameter [in]
- 3 - Number of Rolling Elements
- 4 - Outer Ring Life Factor
- 5 - Inner Ring Life Factor
- 6 - Inner Ring Outer Diameter [in]
- 7 - Outer Ring Inner Diameter [in]
- 8 - Outer Ring Outer Diameter [in]
- 9 - Housing Inner Diameter [in]
- 10 - Outer Ring/Hsg Axial Gap [in]
- 11 - Distance Between Centers [in]
- 12 - Gap Between Outer Rings [in]
- 13 - Axial Preload Force [lbf]
- 14 - Preload Spring Stiff [lbf/in]

For ball and roller bearings, some of the parameters will not need to be input. For instance, a roller bearing will not require information on axial preload force or preload spring stiffness. The life factors are used to estimate inner and outer ring life (in revolutions), and are normally given values of unity. All of the dimensions for ring diameters and axial gaps are passed to FEREBE for use in the nonlinear deflection analysis if the outer ring configuration is one of the unconstrained types.

### Processing Option "L" – Applied Load Definition

Use of this option enables the specification of loads to be applied to the inner ring/shaft along the five axes of inner ring motion. If a roller bearing is currently selected as the bearing type, the program will not allow axial loads to be specified. The five input loads are:

Help for Applied Load Definition

5 parameters require specification:

- 1 - X-Axis (Thrust) Force [lbf]
- 2 - Y-Axis Force [lbf]
- 3 - Z-Axis Force [lbf]
- 4 - XZ-plane Moment [in-lbf]
- 5 - YZ-plane Moment [in-lbf]

### Processing Option "M" – Material Properties

Properties of the materials comprising the shaft, inner ring, rolling elements, outer ring, and carrier/housing are specified with this option. Four parameters for each component are required, and with the English unit system, are listed with the help option as:

Help for Material Property Definition

4 parameters require specification:

- 1 - Elastic Modulus [psi]
- 2 - Poisson Ratio
- 3 - Density [lbm/in<sup>3</sup>]
- 4 - Coeff of Expansion [1/deg F]

For Shaft, Inner Ring, Rolling Elements, Outer Ring, and Carrier/Housing

### Processing Option "O" – Output Request

In order to examine the currently defined model, it is useful to obtain a listing of all defined properties. This option allows such a list to be displayed directly to the screen, which is the default case, or to a file, the name of which can be specified by the user. Only one parameter is required with this option, which is explained by the help option to be:

Help for Model Definition Printout

Only 1 parameter is required:

- F - write model definition to file (default = preban.out)
- S - write model definition to screen

This option is one of the few requests which can be input as a command line. To get a listing to the screen, the string O, S would be input. For output to a file, O, F would be entered, and the program will ask for the name of a file, with the default name of preban.out used.

### Processing Option "P" – Plot Model

PREBAN was initially designed with the intent to provide graphical displays of geometry, loading, and other model definition parameters. The current version does not support such displays, however, this option has been retained for use with future releases.

### Processing Option "Q" – Quit

After all of the desired processing options have been specified, this single character entry is used to terminate execution and exit PREBAN. Accidentally entering this option is not fatal, the program asks if quitting was really the user's intent. If leaving the program was intended, the program determines if an analysis file has been written, and if not, the user is prompted to write an analysis file with the current options. The user is cautioned that the default to this question is to *not* write the analysis file.

### Processing Option "R" – Roller Bearing Definition

Compared to a ball bearing, substantially more data is required to be entered with a roller bearing. A total of 16 quantities need to be input, which are listed by the help option as:

#### Help for Roller Bearing Parameter Definition

16 parameters require specification:

- 1 - Roller Diameter [in]
- 2 - Diametral Clearance [in]
- 3 - Roller Length End-to-End [in]
- 4 - Roller End Sphere Radius [in]
- 5 - Roller Included Angle [deg]
- 6 - Roller Crown Radius [in]
- 7 - Roller Flat Length [in]
- 8 - Outer Race Length [in]
- 9 - Inner Race Length [in]
- 10 - Outer Race Crown Radius [in]
- 11 - Inner Race Crown Radius [in]
- 12 - Flange Inversion Flag (1 - 16)
- 13 - Outer Ring Flange Angle [deg]
- 14 - Inner Ring Flange Angle [deg]
- 15 - Outer Ring End Play [in]
- 16 - Inner Ring End Play [in]

Although requested, parameters 4, 5, and 12 through 16 are not active quantities in the current version of REBANS. The only valid entry for flange inversion flag is unity (1). The end sphere radius, included angle, flange angles, and end play terms should be entered as zero. These quantities are included in the current version of PREBAN in anticipation of future releases of the main analysis program FEREBAS.

Processing Option "S" - Model Summary

This option lists the currently defined analysis options and whether or not enough information has been defined to enable a FEREB A run to be made. A listing from this option lists the current title, input unit system, and status of analysis options, an example of which is as follows:

Summary of Analysis Options

Title used to describe analysis:  
Example title for use with manual

Current unit system in effect is: English

O P T I O N	Defined	Needed
Control Parameters [C] . . . . .	Yes	Yes
General Bearing Parameters [G] . . . . .	Yes	Yes
Ball Bearing Parameters [B]. . . . .	No	No
Roller Bearing Parameters [R]. . . . .	Yes	Yes
Material Properties [M]. . . . .	Yes	Yes
Component Temperature Data [T] . . . . .	No	No
Applied Load Data [L]. . . . .	Yes	Yes
Applied Displacement Data [D]. . . . .	No	No

Bracketed [ ] letter in each option indicates code required for definition

Model as defined is sufficient to run requested analysis

Note the last line of the output. In this particular example, enough information has been defined so that the FEREB A analysis can be run. If insufficient input exists, the following message would appear at the bottom of the summary:

Model as defined is NOT sufficient to run requested analysis  
Options C, G, B or R, L or D, and M require input data

When this message is encountered, a quick examination of the full summary will reveal what options need to be specified.

Processing Option "T" - Temperature Definition

This option permits specification of component temperatures other than at room temperature (70°F in English units), which is the default value. Five values of temperature require entry:

Help for Bearing Temperature Definition

5 parameters require specification:

- 1 - Shaft Temperature [deg F]
- 2 - Inner Ring Temperature [deg F]
- 3 - Element Temperatures [deg F]
- 4 - Outer Ring Temperature [deg F]
- 5 - Carrier/Housing Temp [deg F]

When values other than room temperature are entered, the thermal clearance change module in FEREB A is activated. This routine alters bearing internal and external clearances based upon the difference in temperature from 70°F and the value of thermal expansion coefficient.

### Processing Option "U" – Input Units

Two input unit systems are supported in PREBAN, the tradition English system and the SI or metric system. Before using any of the other input options that require dimensional entry, the unit option can be toggled from one system to the other. Use of this option requires the entry at most of one parameter:

#### Help for Input Unit Option Definition

Format is U[,#] where data in brackets is optional:

U entered alone invokes prompt mode

U, resets to default units (English)

U,# specifically set units, where # is a number. If # is 0 (zero), units are set to English. If # is nonzero (any number), units are set to Metric.

The current entry unit system can be determined at any time by using the "S" option.

### Processing Option "W" – Write Analysis File

The analysis file created by PREBAN can be written at any time during a session. All of the necessary information to make a FEREBAN run need not be defined, in which case PREBAN will inform the user the insufficient data has been written.

The file name of the analysis file is set to rebans.dat by default, although the user is prompted to enter any other name. When this option is requested, the user is first queried as to the use of any existing files:

Do you want to overwrite an existing analysis file? (Y or N, default = N)

If a new file is desired, the following prompts are issued:

Enter the name (and path) of new analysis file (default = rebans.dat)

Analysis data written to file:  
rebans.dat

As with the output summary, the data currently defined is examined to determine if enough information is present to run the desired analysis.

### Processing Option "Z" – Zap (Clear) Analysis Options

The final option in PREBAN permits all of the currently defined analysis options to be cleared and/or reset to default values. Normally, such a drastic action is not required, however, this option is provided as an alternative for exiting and restarting the program. When this option is requested, the program issues the warning:

All defined parameters will be removed, ARE YOU SURE? (Y or N, default = N)

If Y is entered, the zap action will be performed. Note that each individual option may also be reset by entering the letter of the option followed by a separator with no data. The user will be prompted for permission to conduct this operation as well.



### **4.3 Output from PREBAN**

The primary output from PREBAN is the analysis file. This ASCII file contains all of the necessary information used by FEREBAN to run the desired problem. The data in the file is arranged in groups corresponding to keywords such as CONTROL for analysis parameters and MATL PROP for material property definitions. Each of the parameters in the groups are placed on a single line, with each line composed of a numeric quantity and an character descriptor. All data in the analysis file is in the English unit system.

Examining an analysis file with the keyword delimited format is relatively straightforward, and simple changes can be made with a text editor, rather than running PREBAN again. However, bypassing PREBAN to make changes to the analysis file also defeats the PREBAN error checking and is recommended only for experienced users. Examples of analysis files are given in the next two subsections of this chapter.

Finite element model substructure data converted by PREBAN also uses the keyword delimited format in the output ASCII file. The format used to output the structural matrix data has been selected to obtain 17 significant figures of accuracy, the maximum possible with double precision variables on a 32 bit computer. It is assumed that the binary data from ANSYS is also accurate to the same precision.

Both the analysis and substructure data files are written with headers containing the time and date of creation. When PREBAN reads a previously created analysis file, the time and date the file was written are displayed for reference.

### **4.4 Ball Bearing Example Analysis File**

A listing of the analysis file for the first example case, the 60 mm ball bearing, is given on page 4-10. Notice the keyword delimiters and the single line for each parameter, followed by a description of the variable.

Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

Date this analysis file written: Thu Jan 6, 1994

Time this analysis file written: 13:38:06

bbexor3.asc

NO INNER RING FILE

CONTROL

1	Analysis Type
0	Bearing Type (0, 1, or 2)
0	Analysis Units
30.00000	Ring Disp Iteration Loops
0.10000	Ring Disp Iteration Error [%]
50.00000	Force Iteration Loops
1.0000000E-04	Force Iteration Error [%]
2.000000	Analysis Print Flag
3.000000	Outer Ring Configuration
0.000000	Inner Ring Configuration

GENERAL

25000.00	Shaft Speed
3.740200	Bearing Pitch Diameter
12.000000	Number of Rolling Elements
1.000000	Outer Ring Life Multiplier
1.000000	Inner Ring Life Multiplier
2.925100	Inner Ring Outer Diameter
4.555300	Outer Ring Inner Diameter
5.118000	Outer Ring Outer Diameter
5.138000	Carrier/Hsg Inner Diameter
0.1000000	Outer Ring/Hsg Axial Gap
100000.0	Preload Spring Stiffness

BALL BRG

0.8125000	Ball Diameter
5.2000000E-03	Diametral Clearance
0.5200000	Outer Raceway Curvature
0.5800000	Inner Raceway Curvature

MATL PROP

9310	Shaft Material
9310	Inner Ring Material
440C	Elements Material
440C	Outer Ring Material
4340	Car/Hsng Material
3.0000000E+07	Shaft Elastic Modulus
3.0000000E+07	Inner Ring Elastic Modulus
3.0000000E+07	Elements Elastic Modulus
3.0000000E+07	Outer Ring Elastic Modulus
3.0000000E+07	Car/Hsng Elastic Modulus
0.3000000	Shaft Poisson Ratio
0.3000000	Inner Ring Poisson Ratio
0.3000000	Elements Poisson Ratio
0.3000000	Outer Ring Poisson Ratio
0.3000000	Car/Hsng Poisson Ratio
0.2830000	Shaft Density
0.2830000	Inner Ring Density
0.2830000	Elements Density
0.2830000	Outer Ring Density
0.2830000	Car/Hsng Density
8.0000000E-06	Shaft Thermal Exp Coeff
8.0000000E-06	Inner Ring Thermal Exp Coeff
8.0000000E-06	Elements Thermal Exp Coeff
8.0000000E-06	Outer Ring Thermal Exp Coeff
8.0000000E-06	Car/Hsng Thermal Exp Coeff

LOADS

1000.000	X-Axis (Thrust) Force
500.0000	Y-Axis Force
0.0000000E+00	Z-Axis Force
0.0000000E+00	XZ-plane Moment (About Y)
0.0000000E+00	XY-plane Moment (About Z)

Listing of Analysis File for Ball Bearing Example Problem

#### 4.5 Roller Bearing Example Analysis File

For the second example case, the 73 mm roller bearing, the analysis file listing begins on this page and concludes on the following page. With the roller bearing, the addition information regarding geometry makes the file slightly longer than with the ball bearing. Notice that both outer and inner ring ASCII files are specified with this file, compared to the ball bearing example which only uses an outer ring file.

```

Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

Date this analysis file written: Thu Aug 19, 1993

Time this analysis file written: 15:18:42

rbexor8.asc                                rbexir3.asc

CONTROL
      1      Analysis Type
      1      Bearing Type
      0      Analysis Units
    50.00000 Ring Disp Iteration Loops
   0.1000000 Ring Disp Iteration Error [%]
    50.00000 Force Iteration Loops
   1.0000000E-04 Force Iteration Error [%]
    2.000000 Analysis Print Flag
    8.000000 Outer Ring Configuration
    3.000000 Inner Ring Configuration

GENERAL
    25000.00 Shaft Speed
    3.937000 Bearing Pitch Diameter
    12.000000 Number of Rolling Elements
    1.000000 Outer Ring Life Multiplier
    1.000000 Inner Ring Life Multiplier
    3.346400 Inner Ring Outer Diameter
    4.527600 Outer Ring Inner Diameter
    5.000000 Outer Ring Outer Diameter
    5.020000 Carrier/Hsg Inner Diameter
    0.0000000E+00 Outer Ring/Hsg Axial Gap
    0.0000000E+00 Preload Spring Stiffness

ROLLER BRG
    0.5906000 Roller Diameter
    0.0020000 Diametral Clearance
    0.5906000 Roller Length End-to-End
    0.0000000E+00 Roller End Sphere Radius
    0.0000000E+00 Roller Included Angle
    9.0000000E-01 Roller Crown Radius
    0.3000000 Roller Flat Length
    1.202400 Outer Race Length
    1.127500 Inner Race Length
    0.0000000E+00 Outer Race Crown Radius
    0.0000000E+00 Inner Race Crown Radius
    0.0000000E+00 Outer Ring Flange Angle
    0.0000000E+00 Inner Ring Flange Angle
    0.0000000E+00 Outer Ring End Play
    0.0000000E+00 Inner Ring End Play
    1.000000 Flange Inversion Flag

```

Listing of Analysis File for Roller Bearing Example Problem

MATL PROP		
Steel		Shaft Material
9310		Inner Ring Material
440C		Elements Material
9310		Outer Ring Material
Steel		Car/Hsng Material
3.0000000E+07		Shaft Elastic Modulus
3.0000000E+07		Inner Ring Elastic Modulus
3.0000000E+07		Elements Elastic Modulus
3.0000000E+07		Outer Ring Elastic Modulus
3.0000000E+07		Car/Hsng Elastic Modulus
0.3000000		Shaft Poisson Ratio
0.3000000		Inner Ring Poisson Ratio
0.3000000		Elements Poisson Ratio
0.3000000		Outer Ring Poisson Ratio
0.3000000		Car/Hsng Poisson Ratio
0.2830000		Shaft Density
0.2830000		Inner Ring Density
0.2830000		Elements Density
0.2830000		Outer Ring Density
0.2830000		Car/Hsng Density
8.0000000E-06		Shaft Thermal Exp Coeff
8.0000000E-06		Inner Ring Thermal Exp Coeff
8.0000000E-06		Elements Thermal Exp Coeff
8.0000000E-06		Outer Ring Thermal Exp Coeff
8.0000000E-06		Car/Hsng Thermal Exp Coeff
TEMP DATA		
70.00000		Shaft Temperature
70.00000		Inner Ring Temperature
70.00000		Elements Temperature
70.00000		Outer Ring Temperature
70.00000		Car/Hsng Temperature
LOADS		
0.0000000E+00		X-Axis (Thrust) Force
1000.000		Y-Axis Force
0.0000000E+00		Z-Axis Force
0.0000000E+00		XZ-plane Moment
0.0000000E+00		YZ-plane Moment

Listing of Analysis File for Roller Bearing Example Problem, continued

## 5.0 USE INSTRUCTIONS FOR FEREBEBA

The REBANS quasi-static iteration results are determined by the main analysis code FEREBEBA. PREBAN prepares the analysis file and any substructured finite element models, which are read by FEREBEBA. Using the substructured stiffness data, compliance matrices are created and used with modified kinematic relations to determine an equilibrium solution to the applied loads or specified displacements. FEREBEBA is normally run interactively, however, batch mode processing can be used if desired.

Since the quasi-static equilibrium solution is obtained iteratively, the user should be familiar with the nested loop character of the iterative process. Assuming a flexible ring configuration has been specified, there are 4 iterations that must be successfully converged to obtain the final equilibrium solution. Beginning with the innermost loop, the iterative solutions required are:

1. **Rolling element equilibrium** – for each ball or roller in the bearing, local displacements are determined that satisfy the equations for frictionless static equilibrium at each element, using kinematic relations that include ring flexibility.
2. **Inner ring force equilibrium** – contact forces resulting from the rolling element equilibrium solution are summed for all elements and compared to the set of specified global inner ring forces. Assumed inner ring displacements are adjusted until calculated forces match specified forces within the requested relative error or the change in displacements has become "small." If inner ring displacements, rather than forces, have been specified, no iteration is performed.
3. **Outer ring gap closures** – with a converged set of inner ring forces, corresponding element forces on the outer ring are calculated and applied to the compliance matrix at each element position. Deflections resulting from the application of element forces are compared to specified gaps. If the displacements are larger than the gap at any position, a nonlinear iteration is performed to determine whether a gap should be closed or open. A set of elastic outer ring deflections that satisfies the applied loads and any constraints due to closed gaps is returned from this iteration.
4. **Elastic deflection equilibrium** – using the set of outer ring elastic displacements, a companion set of linear inner ring elastic displacements are calculated and both are compared to assumed deflections. A nonlinear iteration routine is used to adjust the assumed deflections until the relative difference with calculated displacements meets the specified error. For each inner and outer ring configuration, the number of elastic displacements is approximately equal to the number of master nodes at each rolling element position times the number of rolling elements. Thus for configurations with a large number of master nodes and rolling elements, a sizable quantity of elastic displacements are produced.

The solution from traditional quasi-static bearing analysis codes is the result of satisfying the equilibrium problems posed by the first two loops. The flexibility enhancements offered by REBANS are reflected by the addition of the third and fourth iteration loops.

## 5.1 Operating FEREBABA

FEREBABA is designed to be run either interactively or batch. Since run times for most analyses with FEREBABA are not exceptionally long, interactive use is not unreasonable. Only two parameters are required for execution – the names of the analysis and output files.

FEREBABA supports command line arguments, with the analysis file specified first, followed by the output file:

```
fereba analfil outfil
```

where `analfil` is the desired analysis file and `outfil` is the corresponding output file. While running, FEREBABA also prints a limited amount of status information, as described in the next subsection, to the default display device, either the console or a batch file.

In batch mode, the command line format can still be used, with appropriate batch mode directives (such as `nohup` on a UNIX system) placed ahead of the `fereba` argument. Also in batch mode, redirection of the status information is advisable, otherwise the operating system default file name will be used. An example of a UNIX batch request is:

```
nohup fereba analfil outfil >fereba.out &
```

where `fereba.out` is the redirected status information file. The ampersand at the end of the command is a UNIX directive to execute in background mode.

The analysis file is obtained from PREBAN. A default name of `rebans.dat` is given to the file by PREBAN, and if not specified on the command line, FEREBABA assumes the same name. The output file is given the default name of `rebans.out` by FEREBABA, and contains an echo of input parameters, as well as any results produced by the analysis code. Specifying print flags larger than 1 (standard output is 0) can result in sizable output files. Standard listings from the two example problems are contained in the last two subsections of this chapter.

It is not necessary to run FEREBABA with a substructure file, in fact, it is recommended that the initial runs be made with inner and outer ring configurations of 0 (zero), which correspond to rigid rings. Subsequent runs can be made using substructure files by editing the analysis file to specify the substructure file name(s) and changing the ring configuration number to one of the values listed in Tables 3-1 and 3-2.

## 5.2 Output from FEREBABA

Results from a FEREBABA analysis are contained in the output file, with the default name of `rebans.out` unless specified differently on the command line. When running, FEREBABA also prints run status information, and example of which is shown on the next page. This status data is designed to keep the user informed of progress during the iteration. Any error messages are directed to the output file and the status display.

-----+  
 R E B A N S - Rolling Element Bearing Analysis System - R E B A N S  
 -----+

```

FFFFF  EEEEE  RRRRR  EEEEE  BBBB  AAAAA
FF      EE      RR RR  EE      BB  BB  AA  AA
FFFFF  EEEEE  RRRRR  EEEEE  BBBB  AAAAAA
FF      EE      RR RR  EE      BB  BB  AA  AA
FF      EEEEE  RR  RR  EEEEE  BBBB  AA  AA
  
```

Flexibility Enhanced Rolling Element Bearing Analysis

Final Release Version 1.10 - Dated 02 June 1994

\*\*\*\*\*

Title Of Analysis Being Run:  
 Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

Name of Input Analysis File: bbex.dat

Name of Output Results File: bbex.out

\*\*\*\*\*

Forming Compliance Matrices for Outer Ring

Reading Matrix Data for: STIFFNESS MATRIX

Matrix Data Read from ASCII File: bbexor3.asc

Reducing 216 DOFs from Outer Ring Stiffness Matrix

Generating Outer Ring Inverse Matrix for 144 DOFs

Compliance Matrices Created for Outer Ring, Elapsed Time = 104.82 secs

\*\*\*\*\*

Now Iterating to Determine Quasi-Static Equilibrium Solution

```

Elastic deformation iteration 1 complete, Max Average Error = 4.8869E+05 %
Elastic deformation iteration 2 complete, Max Average Error = 1.7752E+00 %
Elastic deformation iteration 3 complete, Max Average Error = 6.8844E-01 %
Elastic deformation iteration 4 complete, Max Average Error = 5.2016E-01 %
Elastic deformation iteration 5 complete, Max Average Error = 3.7832E-01 %
Elastic deformation iteration 6 complete, Max Average Error = 2.8075E-01 %
Elastic deformation iteration 7 complete, Max Average Error = 2.1135E-01 %
Elastic deformation iteration 8 complete, Max Average Error = 1.5535E-01 %
Elastic deformation iteration 9 complete, Max Average Error = 8.3751E-01 %
Elastic deformation iteration 10 complete, Max Average Error = 4.8850E-01 %
Elastic deformation iteration 11 complete, Max Average Error = 5.1451E-01 %
Elastic deformation iteration 12 complete, Max Average Error = 6.5219E-01 %
Elastic deformation iteration 13 complete, Max Average Error = 8.6246E-01 %
Elastic deformation iteration 14 complete, Max Average Error = 1.0539E+00 %
Elastic deformation iteration 15 complete, Max Average Error = 2.3097E-01 %
Elastic deformation iteration 16 complete, Max Average Error = 2.0760E-01 %
Elastic deformation iteration 17 complete, Max Average Error = 4.7123E-01 %
Elastic deformation iteration 18 complete, Max Average Error = 1.1220E-01 %
Elastic deformation iteration 19 complete, Max Average Error = 1.1326E-01 %
Elastic deformation iteration 20 complete, Max Average Error = 1.1955E-01 %
Elastic deformation iteration 21 complete, Max Average Error = 3.6877E-01 %
Elastic deformation iteration 22 complete, Max Average Error = 1.8032E-01 %
Elastic deformation iteration 23 complete, Max Average Error = 1.1117E-01 %
Elastic deformation iteration 24 complete, Max Average Error = 7.4076E-02 %
  
```

Quasi-Static Iteration Finished - Elapsed Execution Time = 161.46 secs

\*\*\*\*\*

FEREBA Execution Completed, Total CP Time = 162.89 secs

All Output Written to File: bbex.out

\*\*\*\*\*

Example of FEREBAS status information printout

### 5.3 Convergence Problems

Due to the nature of the iterative analysis performed by FEREBÄ, absolute convergence can not be guaranteed. Usually the inner ring force iteration is reliable, seldom will the program be unable to obtain a solution. The outermost elastic displacement iteration is much more volatile, and may have difficulties in converging.

Particular attention is warranted when convergence errors are encountered, since the resulting solution may not be valid. Difficulties in obtaining a solution may be encountered in all four iteration loops, and in some instances the analysis may be rerun to obtain convergence by modifying iteration parameters contained in the analysis file. Some typical iteration convergence errors and suggested remedies are as follows:

ERROR FROM DNEQNF - The number of calls to FCN has exceeded ITMAX\*(N+1).  
ERROR FROM DNEQNF - The iteration has not made good progress.

These errors are from the rolling element equilibrium iteration, which has program determined accuracy and loop limits. No user action can be taken, since errors of this type usually imply serious problems with the solution have been encountered. Normally, execution will be stopped automatically when errors of this type have been detected. Activating print option level 3 will display information specific to the rolling element equilibrium iteration.

WARNING - Forces not in equilibrium after ?? iterations - WARNING  
Maximum error XXXXXX% (requested YYYYYY%) residuals are:  
(111111111 222222222 333333333 444444444 555555555)  
WARNING - Solution valid if residuals are small enough - WARNING

This error is from the inner ring force equilibrium iteration, with user defined accuracy and loop limits. The residuals are the differences between specified and calculated forces. Increasing the number of iterations and/or relaxing the requested error may result in a converged solution. Execution will continue, however, the forces calculated may be so far away from a valid solution that further gap and elastic deflection calculations will be pointless. Specifying print option level 2 will provide information on the force iteration.

ERROR - Outer Ring/Carrier Gap Iteration Limit Reached - ERROR  
ERROR - Resulting Elastic Deflections are Probably Invalid - ERROR

If the outer ring gap iteration is unable to obtain a set of constrained gaps that match the applied rolling element forces, this error message is issued. The number of iterations is set by the program, and the user will be unable to alter the iteration. Execution will continue, however, the elastic deflections that result from exceeding the iteration are probably invalid. Changing the print option to 1 will result in more diagnostic details regarding the gap iteration.

WARNING - Elastic deformations unconverged after ?? loops - WARNING  
Outer ring deformation error is = XXXXXXXX%  
Inner ring deformation error is = YYYYYYYY%  
Requested maximum iteration error is = ZZZZZZZZ%  
WARNING - Solution may be acceptable - examine carefully - WARNING

This warning is given if the number of elastic deformation loops is exceeded and the relative errors are not below the user specified value. Increasing the number of allowed iterations and/or increasing the desired error may result in a converged solution. Successive iterates in any given run stream are printed by the program in the status information, and a reasonable solution may be obtained by setting the number of iterations to a value that yielded a relatively low error.



## 5.4 Ball Bearing Example Output File

This page and the next six pages contain a listing of the standard output from a FEREB A run, in this case for the ball bearing example problem. The first four pages are an echo of the input data contained in the analysis file, the final three pages are the calculated results. Note that this output file is formatted to fit on 8½" x 11" paper.

```

+-----+
| R E B A N S - Rolling Element Bearing Analysis System - R E B A N S |
+-----+

      FFFFFFFF  EEEEEEE  RRRRRR  EEEEEEE  BBBB  B  AAAA
      FF        EE       RR  RR  EE       BB  BB  AA  AA
      FFFFFFFF  EEEEEEE  RRRRRR  EEEEEEE  BBBB  B  AAAAAA
      FF        EE       RR  RR  EE       BB  BB  AA  AA
      FF        EEEEEEE  RR  RR  EEEEEEE  BBBB  B  AA  AA

      Flexibility Enhanced Rolling Element Bearing Analysis
      - - - - -

      Final Release Version 1.10 - Dated 02 June 1994

*****
Title of this analysis:
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

This FEREB A analysis started on Fri Jun 3, 1994 at 11:21:29

- - - - - A N A L Y S I S   D E S C R I P T I O N   - - - - -

Requested Analysis . . . . . Quasi-Static
Elastic Deformation Iteration Limit. . . . . 30 loops
Elastic Deformation Iteration Accuracy . . . . . 1.0E-1 percent
Inner Ring Force Iteration Limit . . . . . 50 loops
Inner Ring Force Iteration Accuracy. . . . . 1.0E-4 percent

** Page FEREB A-1 **

```

The second page of output from FEREB A contains the general description of the bearing analyzed, including data specific to the ball bearing for this example problem.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

- - - - - G E N E R A L   B E A R I N G   D E S C R I P T I O N - - - - -

Bearing Type Analyzed . . . . . Ball Bearing
Inner Ring/Shaft Speed. . . . . 25000 rpm
Number of Rolling Elements. . . . . 12
Pitch Diameter. . . . . 3.7402 inches
Outer Ring Life Multiplier. . . . . 1.000
Inner Ring Life Multiplier. . . . . 1.000
Inner Ring Outer Diameter . . . . . 2.9251 inches
Outer Ring Inner Diameter . . . . . 4.5553 inches
Outer Ring Outer Diameter . . . . . 5.1180 inches
Carrier/Hsg Inner Diameter. . . . . 5.1380 inches
Outer Ring/Housing Axial Gap. . . . . 0.1000 inches
Axial Preload Spring Stiffness. . . . . 100. Klbf/in

- - - - - R O L L I N G   E L E M E N T   D A T A - - - - -

Ball Diameter . . . . . 0.8125 inches
Diametral Clearance . . . . . 0.0052 inches
Outer Raceway Curvature . . . . . 0.5200
Inner Raceway Curvature . . . . . 0.5800

** Page FEREB A-2 **

```

Page 2 of FEREB A output for ball bearing example problem

The third page of output from FEREB A contains material and temperature information. Although no temperature data was specified, note that the program sets the temperature of all components to room temperature.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

----- MATERIAL PROPERTIES -----

Shaft Material Designation . . . . . 9310
Inner Ring Material Designation. . . . . 9310
Rolling Element Material Designation . . . . . 440C
Outer Ring Material Designation. . . . . 440C
Carrier/Housing Material Designation . . . . . 4340

      Shaft      Inner Ring      Rolling Element      Outer Ring      Carrier/
      -----      -----      -----      -----      -----
Elastic Modulus (Ksi)      30000.      30000.      30000.      30000.      30000.
Poisson's Ratio            0.3000      0.3000      0.3000      0.3000      0.3000
Density (lbm/in3)          0.2830      0.2830      0.2830      0.2830      0.2830
Thermal Exp Coef (1/F)     8.0E-6      8.0E-6      8.0E-6      8.0E-6      8.0E-6

----- COMPONENT TEMPERATURES -----

Shaft Temperature . . . . . 70.0 F
Inner Ring Temperature. . . . . 70.0 F
Rolling Element Temperature . . . . . 70.0 F
Outer Ring Temperature. . . . . 70.0 F
Carrier/Housing Temperature . . . . . 70.0 F

** Page FEREB A-3 **

```

Page 3 of FEREB A output for ball bearing example problem

The fourth page of output from FEREBEA lists the applied loads and any finite element model files used. If applied displacements were given, the input values would be printed rather than loads. In this particular example, no inner ring file was used, and the program indicates this option as shown in the listing.

```

+-----+
+  R E B A N S  -  Rolling Element Bearing Analysis System  -  R E B A N S  +
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

-----  A P P L I E D    I N N E R    R I N G    L O A D S  -----

Force in X-direction (thrust) . . . . . 1000.0 lbf
Force in Y-direction. . . . . 500.0 lbf
Force in Z-direction. . . . . 0.0 lbf
Moment in XZ-plane (about Y-axis) . . . . . 0.0 in-lbf
Moment in XY-plane (about Z-axis) . . . . . 0.0 in-lbf

-----  F I N I T E    E L E M E N T    M O D E L    D A T A  -----

Outer Ring Configuration. . . . . 3
Inner Ring Configuration. . . . . 0
Outer Ring ASCII File:  bbexor3.asc
Inner Ring ASCII File:  NO INNER RING FILE

** Page FEREBEA-4 **

```

Page 4 of FEREBEA output for ball bearing example problem

The fifth page of output from FEREB A contains the first information about iteration results. Three separate pieces of data are presented – a summary of iteration parameters, the final values of inner ring displacements, and a life estimate.

```

+-----+
+  R E B A N S  -  Rolling Element Bearing Analysis System  -  R E B A N S  +
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

- - - - - I T E R A T I O N   R E S U L T S   S U M M A R Y   - - - - -

Required elastic deflection loops . . . . .      24
Outer ring deflection accuracy. . . . .  7.4E-2 percent
Inner ring deflection accuracy. . . . .  0.0E+0 percent
Maximum number of force iteration loops . . . . .      18
Final force iteration accuracy. . . . .  4.3E-3 percent

-  C A L C U L A T E D   I N N E R   R I N G   D I S P L A C E M E N T S   -

Translation in X-direction (axial). . . . .  0.01358 inches
Translation in Y-direction. . . . .  0.01222 inches
Translation in Z-direction. . . . .  0.00014 inches
Rotation in XZ-plane (about Y-axis) . . . . .  0.00000 radians
Rotation in XY-plane (about Z-axis) . . . . .  0.00304 radians

- - - - - F A T I G U E   L I F E   P R E D I C T I O N   - - - - -

Outer Ring Life . . . . .  7.84E+08 revs
Inner Ring Life . . . . .  2.06E+08 revs
Overall Bearing Life. . . . .  1.72E+08 revs

** Page FEREB A-5 **

```

Page 5 of FEREB A output for ball bearing example problem

The sixth page of output from FEREB A presents the contact loads and elastic deflections calculated for the bearing system. Note that the inner ring elastic deflections are zero, since no inner ring finite element model was used.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

----- CONTACT FORCES & ANGLES -----

Ball      Azimuth      Normal Forces (lbf)      Contact      Contact
(deg)      Outer      Inner      Angles (deg)      Stress (psi)
-----
1         0.00         896.4      496.9      7.71      14.02      258125.      342091.
2         30.00        742.1      342.2      6.84      14.97      242366.      302089.
3         60.00        620.1      220.2      6.01      17.15      228286.      260817.
4         90.00        601.6      203.2      6.53      19.66      225995.      253932.
5        120.00        600.0      203.7      7.34      22.09      225795.      254122.
6        150.00        625.2      231.3      8.55      23.70      228906.      265131.
7        180.00        628.4      235.4      8.88      24.33      229299.      266667.
8        210.00        621.2      227.3      8.47      23.73      228420.      263566.
9        240.00        605.5      209.4      7.46      22.07      226482.      256455.
10       270.00        595.4      196.9      6.40      19.71      225210.      251252.
11       300.00        621.6      221.8      6.04      17.16      228470.      261424.
12       330.00        746.4      346.5      6.89      14.96      242835.      303365.

----- ELASTIC RING DEFORMATIONS -----

Ball      Azimuth      +--- Outer Ring (in) ---+      +--- Inner Ring (in) ---+
(deg)      Axial      Radial      Axial      Radial
-----
1         0.00         0.010116      0.010117      0.000000      0.000000
2         30.00        0.010116      0.009054      0.000000      0.000000
3         60.00        0.010071      0.005538      0.000000      0.000000
4         90.00        0.010032      0.000434      0.000000      0.000000
5        120.00        0.010023      -0.004635      0.000000      0.000000
6        150.00        0.010036      -0.008414      0.000000      0.000000
7        180.00        0.010045      -0.009809      0.000000      0.000000
8        210.00        0.010037      -0.008538      0.000000      0.000000
9        240.00        0.010024      -0.004900      0.000000      0.000000
10       270.00        0.010031      0.000177      0.000000      0.000000
11       300.00        0.010070      0.005290      0.000000      0.000000
12       330.00        0.010117      0.008903      0.000000      0.000000

** Page FEREB A-6 **

```

Page 6 of FEREB A output for ball bearing example problem

The seventh and final page of output from FEREBE lists rolling element speeds in the three rolling element centered coordinates. Total and orbital speeds are also given. Note that the elapsed run time is printed at the end of the listing for reference.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 1, 12 Ball 60mm Bearing, IBSCOR = 3, Fa = 1000, Fr = 500, 25Krpm

----- R O L L I N G   E L E M E N T   S P E E D S -----

Ball   Azimuth  +--- Element Relative Angular Speeds (radians/second) ---+
      (deg)  Axial    Radial   Tangential   Total      Orbital
-----
  1     0.00    5716.32  -596.59     6.13     5747.37    1026.91
  2    30.00    5716.01  -600.36     6.17     5747.46    1026.94
  3    60.00    5715.44  -608.24     6.25     5747.71    1027.02
  4    90.00    5714.64  -617.76     6.34     5747.94    1027.10
  5   120.00    5713.67  -627.98     6.45     5748.08    1027.17
  6   150.00    5712.55  -637.57     6.55     5748.02    1027.20
  7   180.00    5712.16  -640.83     6.58     5748.00    1027.21
  8   210.00    5712.66  -636.60     6.54     5748.02    1027.20
  9   240.00    5713.70  -627.24     6.44     5748.03    1027.16
 10   270.00    5714.72  -616.86     6.34     5747.92    1027.09
 11   300.00    5715.46  -607.68     6.24     5747.68    1027.01
 12   330.00    5716.06  -599.77     6.16     5747.44    1026.94

** Page FEREBE-7 **

*****
FEREBE Execution Completed, Total CP Time = 162.89 secs
*****

```

Page 7 of FEREBE output for ball bearing example problem

## 5.5 Roller Bearing Example Output File

This page and the next six pages contain a listing of the output from the FEREB A run for the roller bearing example problem. As with the ball bearing example, the first four pages echo the input data, and the final three pages are the calculated results.

```
+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+

      FFFFFFFF  EEEEEEE  RRRRRR  EEEEEEE  BBBB BB  AAAAA
      FF        EE        RR  RR  EE        BB  BB  AA  AA
      FFFFFF    EEEEEEE  RRRRRR  EEEEEEE  BBBB BB  AAAAAA
      FF        EE        RR  RR  EE        BB  BB  AA  AA
      FF        EEEEEEE  RR  RR  EEEEEEE  BBBB BB  AA  AA

      Flexibility Enhanced Rolling Element Bearing Analysis
      Final Release Version 1.10 - Dated 02 June 1994
*****
Title of this analysis:
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

This FEREB A analysis started on Fri Jun  3, 1994 at 13:00:45

----- A N A L Y S I S   D E S C R I P T I O N -----

Requested Analysis . . . . . Quasi-Static
Elastic Deformation Iteration Limit. . . . . 50 loops
Elastic Deformation Iteration Accuracy . . . . 1.0E-1 percent
Inner Ring Force Iteration Limit . . . . . 50 loops
Inner Ring Force Iteration Accuracy. . . . . 1.0E-4 percent

** Page FEREB A-1 **
```

Page 1 of FEREB A output for roller bearing example problem



The second page of output from FEREB A contains the general description of the bearing analyzed, including data specific to the roller bearing for this example problem.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

- - - - - G E N E R A L   B E A R I N G   D E S C R I P T I O N - - - - -
Bearing Type Analyzed . . . . . Roller Bearing
Flange Type Number. . . . . 1
Inner Ring/Shaft Speed. . . . . 25000 rpm
Number of Rolling Elements. . . . . 12
Pitch Diameter. . . . . 3.9370 inches
Outer Ring Life Multiplier. . . . . 1.000
Inner Ring Life Multiplier. . . . . 1.000
Inner Ring Outer Diameter . . . . . 3.3464 inches
Outer Ring Inner Diameter . . . . . 4.5276 inches
Outer Ring Outer Diameter . . . . . 5.0000 inches
Carrier/Hsg Inner Diameter. . . . . 5.0200 inches

- - - - - R O L L I N G   E L E M E N T   D A T A - - - - -
Roller Diameter . . . . . 0.5906 inches
Diametral Clearance . . . . . 0.0020 inches
Roller Length . . . . . 0.5906 inches
Roller Profile Flat Length. . . . . 0.3000 inches
Roller Crown Radius . . . . . 0.9000 inches
Roller End Sphere Radius. . . . . 0.0000 inches
Roller Included Angle . . . . . 0.0000 degrees

           Outer Raceway      Inner Raceway
Effective Length . . . . . 1.2024      1.1275 inches
Crown Radius . . . . . 0.0000      0.0000 inches
Axial Play . . . . . 0.0000      0.0000 inches
Flange Angle . . . . . 0.00      0.00 degrees
Osculation . . . . . 0.0000      0.0000

```

\*\* Page FEREB A-2 \*\*

Page 2 of FEREB A output for roller bearing example problem

The third page of output from FEREBEBA contains material and temperature information. Temperature data was specified in the analysis file for all components equal to room temperature.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

-----
M A T E R I A L   P R O P E R T I E S   -----

Shaft Material Designation . . . . . Steel
Inner Ring Material Designation. . . . . 9310
Rolling Element Material Designation . . . . . 440C
Outer Ring Material Designation. . . . . 9310
Carrier/Housing Material Designation . . . . . Steel

          Shaft      Inner Ring      Rolling Element      Outer Ring      Carrier/
          -----      -----      -----      -----      Housing
          -----      -----      -----      -----      -----
Elastic Modulus (Ksi)      30000.      30000.      30000.      30000.      30000.
Poisson's Ratio            0.3000      0.3000      0.3000      0.3000      0.3000
Density (lbm/in3)          0.2830      0.2830      0.2830      0.2830      0.2830
Thermal Exp Coef (1/F)     8.0E-6      8.0E-6      8.0E-6      8.0E-6      8.0E-6

-----
C O M P O N E N T   T E M P E R A T U R E S   -----

Shaft Temperature . . . . . 70.0 F
Inner Ring Temperature. . . . . 70.0 F
Rolling Element Temperature . . . . . 70.0 F
Outer Ring Temperature. . . . . 70.0 F
Carrier/Housing Temperature . . . . . 70.0 F

** Page FEREBEBA-3 **

```

Page 3 of FEREBEBA output for roller bearing example problem

The fourth page of output from FEREBEBA lists the applied loads and any finite element model files used. An inner ring file is used in this example, as listed by the program.

```
+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

----- APPLIED INNER RING LOADS -----

Force in X-direction (thrust) . . . . . 0.0 lbf
Force in Y-direction. . . . . 1000.0 lbf
Force in Z-direction. . . . . 0.0 lbf
Moment in XZ-plane (about Y-axis) . . . . . 0.0 in-lbf
Moment in XY-plane (about Z-axis) . . . . . 0.0 in-lbf

----- FINITE ELEMENT MODEL DATA -----

Outer Ring Configuration. . . . . 8
Inner Ring Configuration. . . . . 3
Outer Ring ASCII File: rbexor8.asc
Inner Ring ASCII File: rbexir3.asc

** Page FEREBEBA-4 **
```

Page 4 of FEREBEBA output for roller bearing example problem

The fifth page of output from FEREBEBA contains the first information about iteration results. Three separate pieces of data are presented – a summary of iteration parameters, the final values of inner ring displacements, and a life estimate. Note that the nonlinear outer ring iteration accuracy is significantly larger than the linear inner ring error.

```

+-----+
+  R E B A N S - Rolling Element Bearing Analysis System - R E B A N S  +
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

- - - - - I T E R A T I O N   R E S U L T S   S U M M A R Y   - - - - -

Required elastic deflection loops . . . . .      23
Outer ring deflection accuracy. . . . .  8.3E-2 percent
Inner ring deflection accuracy. . . . .  2.6E-4 percent
Maximum number of force iteration loops . . . . .      10
Final force iteration accuracy. . . . .  1.2E-3 percent

- C A L C U L A T E D   I N N E R   R I N G   D I S P L A C E M E N T S   -

Translation in X-direction (axial). . . . .  0.00000 inches
Translation in Y-direction. . . . .  0.01148 inches
Translation in Z-direction. . . . .  0.00000 inches
Rotation in XZ-plane (about Y-axis) . . . . .  0.00000 radians
Rotation in XY-plane (about Z-axis) . . . . .  0.00000 radians

- - - - - F A T I G U E   L I F E   P R E D I C T I O N   - - - - -

Outer Ring Life . . . . .  6.66E+05 revs
Inner Ring Life . . . . .  1.30E+05 revs
Overall Bearing Life. . . . .  1.14E+05 revs

** Page FEREBEBA-5 **

```

Page 5 of FEREBEBA output for roller bearing example problem

The sixth page of output from FEREB A presents the contact loads and elastic deflections calculated for the bearing system. In this example, the inner ring is virtually unloaded, except at the element where the load is applied, which implies the bearing will probably skid under this load and clearance combination. Since both the inner and outer rings were represented with finite element models, both sets of elastic deflections are non-zero.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

- - - - - C O N T A C T   F O R C E S   &   A N G L E S   - - - - -

Roller  Azimuth  Normal Forces (lbf)  Contact  Contact
        (deg)    Outer      Inner      Angles (deg)  Stress (psi)
        -----  -----  -----  -----  -----
1         0.00      2162.5    1000.0    0.00      0.00      166693.    136160.
2         30.00     1161.8      0.0      0.00      0.00      122182.      0.
3         60.00     1159.4      0.0      0.00      0.00      259322.      0.
4         90.00     1156.4      0.0      0.00      0.00      258852.      0.
5        120.00     1156.4      0.0      0.00      0.00      258851.      0.
6        150.00     1156.4      0.0      0.00      0.00      258850.      0.
7        180.00     1156.4      0.0      0.00      0.00      258850.      0.
8        210.00     1156.4      0.0      0.00      0.00      258850.      0.
9        240.00     1156.4      0.0      0.00      0.00      258851.      0.
10       270.00     1156.4      0.0      0.00      0.00      258853.      0.
11       300.00     1159.4      0.0      0.00      0.00      259325.      0.
12       330.00     1161.7      0.0      0.00      0.00      122179.      0.

- - - - - E L A S T I C   R I N G   D E F O R M A T I O N S   - - - - -

Roller  Azimuth  +--- Outer Ring (in) ---+  +--- Inner Ring (in) ---+
        (deg)    Radial - L      Radial - R      Radial - L      Radial - R
        -----  -----  -----  -----  -----
1         0.00      0.010104      0.010104      0.000217      0.000217
2         30.00     0.008968      0.008968      0.000065      0.000065
3         60.00     0.005617      0.005618      0.000014      0.000014
4         90.00     0.000837      0.000837      0.000002      0.000002
5        120.00    -0.004045     -0.004045     0.000000      0.000000
6        150.00    -0.007681     -0.007681     0.000000      0.000000
7        180.00    -0.008990     -0.008990     0.000000      0.000000
8        210.00    -0.007631     -0.007631     0.000000      0.000000
9        240.00    -0.003980     -0.003980     0.000000      0.000000
10       270.00     0.000891      0.000891      0.000002      0.000002
11       300.00     0.005687      0.005688      0.000014      0.000014
12       330.00     0.009008      0.009008      0.000065      0.000065

** Page FEREB A-6 **

```

Page 6 of FEREB A output for roller bearing example problem

The seventh and final page of output from FEREBAs lists rolling element speeds in the three rolling element centered coordinates. Total and orbital speeds are also given. For a roller bearing, the predominate angular velocity is in the axial direction. Note that the elapsed run time printed at the end of the listing is significantly shorter than required for the ball bearing example, due to the much more difficult force and gap iterations required for the combined loading placed on the ball bearing system.

```

+-----+
R E B A N S - Rolling Element Bearing Analysis System - R E B A N S
+-----+
Example Case 2, 12 roller 73mm Bearing, OR/IR = 8/3, Fr = 1000, 25K rpm

- - - - - R O L L I N G   E L E M E N T   S P E E D S   - - - - -

Roller  Azimuth  +--- Element Relative Angular Speeds (radians/second) ---+
      (deg)  Axial      Radial      Tangential      Total      Orbital
-----
 1      0.00    17059.08      0.00      0.00      17059.08    2225.26
 2     30.00    17059.08      0.00      0.00      17059.08    2225.26
 3     60.00    17059.08      0.08      0.00      17059.08    2225.26
 4     90.00    17059.08      0.00      0.00      17059.08    2225.26
 5    120.00    17059.08      0.00      0.00      17059.08    2225.26
 6    150.00    17059.08      0.00      0.00      17059.08    2225.26
 7    180.00    17059.08      0.00      0.00      17059.08    2225.26
 8    210.00    17059.08      0.00      0.00      17059.08    2225.26
 9    240.00    17059.08      0.00      0.00      17059.08    2225.26
10    270.00    17059.08      0.00      0.00      17059.08    2225.26
11    300.00    17059.08      0.08      0.00      17059.08    2225.26
12    330.00    17059.08      0.00      0.00      17059.08    2225.26

** Page FEREBAs-7 **

*****
FEREBAs Execution Completed, Total CP Time = 34.21 secs
*****

```

Page 7 of FEREBAs output for roller bearing example problem



# REPORT DOCUMENTATION PAGE

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title And Subtitle  Modeling of Rolling Element Bearing Mechanics			5. Report Date October 1994		
			6. Performing Organization Code		
7. Author(s)  L. M. Greenhill D. K. Merchant			8. Performing Organization Report No.		
			10. Work Unit No.		
9. Performing Organization Name and Address  Aerojet P.O. Box 13222 Sacramento, CA 95813-6000			11. Contract or Grant No. NAS 8-38607		
			13. Type of Report and Period Covered Final Report - User's Manual		
12. Sponsoring Agency Name and Address  Aerojet Sacramento Operations P.O. Box 1322 Sacramento, California 95813-6000			14. Sponsoring Agency Code		
			15. Supplementary Notes  Code development and documentation of the described rolling element bearing analysis codes were led by Rotordynamics-Seal Research, with support from Aerojet.  The NASA technical monitor is S. Ryan, MSFC/ED14.		
16. Abstract  This report provides the user's manual for the Rolling Element Bearing Analysis System (REBANS) analysis code which determines the quasi-static response to external loads or displacement of three types of high-speed rolling element bearings: angular contact ball bearings, duplex angular contact ball bearings, and cylindrical roller bearings. The model includes the defects of bearing ring and support structure flexibility. It is comprised of two main programs: the Preprocessor for Bearing Analysis (PREBAN) which creates the input files for the main analysis program, and Flexibility Enhanced Rolling Element Bearing Analysis (FEREBA), the main analysis program. This report addresses input instructions for and features of the computer codes. A companion report addresses the theoretical basis for the computer codes. REBANS extends the capabilities of the SHABERTH (Shaft and Bearing Thermal Analysis) code to include race and housing flexibility, including such effects as dead band and preload springs.					
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